Journal of
Experimental Psychology

VOL. 28, NO. 5 MAY, 1941

CONDITIONING THE OCCIPITAL ALPHA RHYTHM IN MAN

BY HERBERT JASPER AND CHARLES SHAGASS

McGill University and the Montreal Neurological Institute

Several investigators have observed that the occipital alpha rhythm of the human electroencephalogram (E.E.G.) can be depressed or blocked by sound, a previously indifferent stimulus, if it has been repeatedly paired with light, the usual unconditioned stimulus (Durup and Fessard, **8**), (Loomis, Harvey and Hobart, **18**), (Jasper and Cruikshank, **17**), (Cruikshank, **7**). This conditioning of the electrical activity of the occipital cortex to a sound stimulus was observed during the course of other experiments. Cruikshank found, while investigating the latency of alpha block to various light intensities, that a preparatory sound signal, given repeatedly at equal intervals before a light, established in a short while what appeared to be a conditioned response (CR) to the constant time interval, sound-light. Walter (**29**) has spoken of this as 'time conditioning.'

The alpha block has been studied as a simple CR by Loomis, Harvey and Hobart (**18**) with a low tone as the conditioned stimulus. The simple CR to a tone has also been quantitatively studied by Travis and Egan (**28**), who reached the conclusion that the alpha block can be converted into an unstable CR.

Responses which can be conditioned in the classical Pavlovian fashion have been divided into 3 groups by Hilgard and Marquis (**13**). (1), Glandular, smooth muscle and blood responses: such as salivation, galvanic skin response, immunity reaction, nausea and diuresis; (2) relatively involuntary responses in striate muscle: such as flexor reflex, eye movements and change in respiration; (3) semi-voluntary and voluntary responses, such as withdrawal movements to shock, locomotion, and instructed responses. There is some suggestion that a fourth class, 'sensorial responses,' might be added, according to the recent work of Bogoslovski (**4**).

It would be necessary to provide a fifth group, for the response here studied, inasmuch as we are dealing with the electrical activity

of the cortical centres themselves. Insofar as we know, the occipital alpha rhythm is independent of peripheral effectors. Although related fundamentally to the visual afferent system the depression of the occipital alpha rhythm is a centrally determined response since it can be induced by hypnosis, attention, etc. (Loomis, Harvey and Hobart, **19**), (Jasper and Cruikshank, **17**).

The purpose of this study has been two-fold. First, to investigate extensively the depression (blocking) of the alpha rhythm in man as a conditioned response; second, to appraise the value of the electroencephalograph as an instrument for the study of conditioning problems, especially in man. The alpha block has here been studied as a response with relation to simple, cyclic, delayed, trace, differential, differential delayed, and backward conditioning.

Technique

Apparatus

A standard amplifier and ink-writing oscillograph were used for brain potential recording. Additional pens were employed for indicating various signals (stimuli and manual responses) on the E.E.G. record. Sound frequencies between 400 and 700 d.v. per second were generated by a beat frequency oscillator. The voltage output was kept constant in all experiments. The light used was a 6 volt flashlight bulb 12 inches in front of the subject's eyes. For manual response, a push button connected to an electromagnetic marker was employed. All stimuli were controlled from outside the sound-proof room used for the subject.

Subjects

There were 34 subjects in all, 24 of whom were male college students. Those with the most regular and continuous alpha rhythm were used repeatedly for different types of experiments. All were unaware of the nature of the experiment to begin with, although some few interpreted it as conditioning.

Procedure

Two electrodes were applied by means of collodion, one to the right occipital area and the other to the right ear. This provided monopolar recording of the occipital brain potentials. The subject was placed on a bed in a completely dark, sound-proof, electrically shielded room. Several sound stimuli were presented in order to avoid the 'startle' effect of sound on the alpha. Then 5 or 6 control trials with sound alone were made. In the backward CR experiments which required some manual response to sound, the subject was told to press the button at every sound he heard.

In all other experiments, following control trials with sound alone, the subject was told to press the button as soon as he could whenever he saw a light, but to remain as relaxed as possible at all times. The manual response alone usually had no effect on the alpha rhythm, as previously shown by Adrian and Matthews (**1**) and Jasper and Cruikshank (**17**).[1]

A slow speed of 1 cm per sec. was used in recording because this made for easy visibility of the alpha block. The durations of stimuli, due to lack of an automatic timing device, varied in all experiments ± 0.3 sec. Test trials were given in random order. The interval between all trials was varied, except of course in cyclic CR, so as to avoid cyclic conditioning.

---

[1] The manual response was introduced because, in preliminary experiments, it was found extremely difficult to obtain a clearly visible CR when the subject remained passive. The effect obtained was in some respects similar to that of Miller and Cole (**21**) where a more rapid and stable CR was obtained when it was integrated into an action context.

Conditioning was considered established when at least 2 consecutive responses to the conditioned stimulus occurred in which there was a sufficiently long depression of the alpha rhythm to be clearly a response to the stimulus rather than a 'spontaneous' variation.

Results

Simple Conditioned Responses

The first simple conditioned response (CR) was established in about ten paired presentations of sound and light stimuli. Sound alone produced no appreciable effect on the alpha rhythm in control trials before the conditioning was started after initial startle effects were overcome. In the conditioning trials a 500 cycle sound stimulus preceded by 0.7 sec. the light stimulus which lasted 5.3 sec. The sound overlapped the light.

The latent period of the unconditioned alpha block to light was about 0.5 sec. while the latent period of the conditioned response to sound was about the same or slightly longer. (Accurate studies of latency were not possible from records taken at the slow rate of speed used.) The alpha rhythm dropped out just as completely with the conditioned sound stimulus as with the light and the block was of comparable duration (Fig. 1). This CR was not very stable but five consecutive responses were obtained in one subject. In some experiments extinction occurred after as few as three conditioned responses without reinforcement.

Cyclic CR

The periodic repetition of a 4.7 sec. light stimulus with equal intervals of 9.2 seconds between each stimulus resulted in the establishment of a cyclic CR in 10 to 20 trials.[2] In this case the alpha rhythm was blocked following the conditioned time interval without an external stimulus. Actually the cyclic conditioned response usually occurred earlier than the conditioned interval since it was anticipatory (Fig. 2).

The CR was as complete but usually longer than the unconditioned response to light. In one subject after conditioning a CR occurred lasting 90 sec. during which time 7 periodic light stimuli were introduced before the reappearance of the alpha waves. The prolongation of the CR may have been related to a change in emotional attitude of the subject. Cyclic repetition of a stimulus may produce an attitude of expectancy so that a long lasting disturbance is caused by omission of a stimulus in the regular series. Prolonged depression of the alpha rhythm due to emotional disturbances were encountered

[2] The number of trials includes test trials.

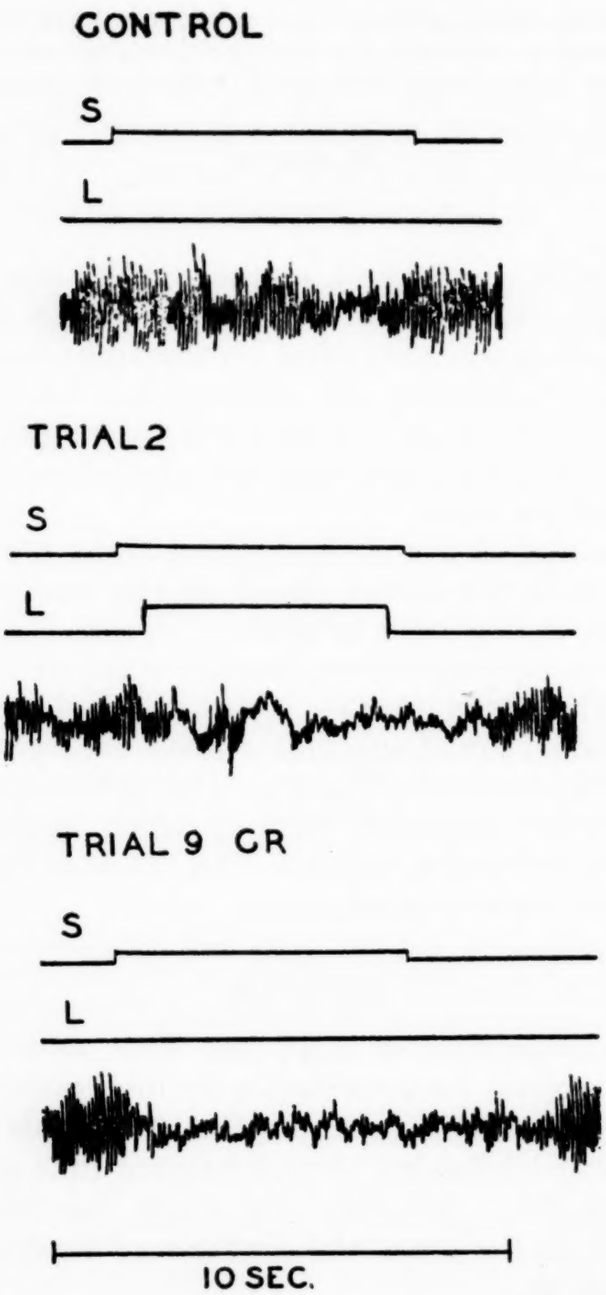


FIG. 1. *Simple CR.* CONTROL shows sound (*S*) without light (*L*) had no effect on alpha waves. (The short depression of the alpha in this sample was similar to 'spontaneous' changes throughout the record in this subject.) TRIAL 2 was second conditioning trial. TRIAL 9 shows blocking of alpha rhythm as CR to sound.

in other experiments but were usually removed after a few reinforced trials.

Extinction of a cyclic CR can be observed only by allowing a long interval to elapse without stimulation, until no further CRs are observed, since 'time' is the conditioned stimulus. In our experiments, after at least 40 to 50 conditioning trials, 2 to 4 successive

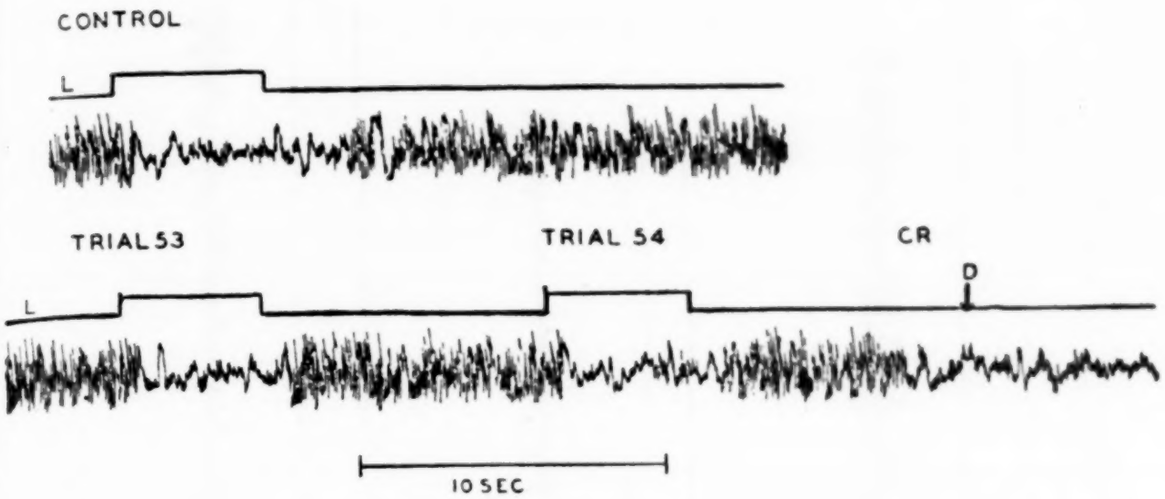


FIG. 2. *Cyclic CR.* CONTROL with single light (*L*) shows no tendency for cyclic repetition of alpha response after light was turned off before conditioning. After 54 repetitions of light at a constant interval (9.4 sec.) one stimulus was omitted at *D* following anticipatory blocking of alpha rhythm which did not return for 90 sec.

cyclic conditioned responses were obtained before extinction, when no reinforcing external stimulus was presented.

Delayed CR

Continuous presentation of sound for some time before light and overlapping it in repeated conditioning trials resulted in a delayed conditioned response to sound (Fig. 3). With delays of the order of 10 sec. a delayed CR was established in about 20 trials. The duration of the sound before the light varied in different experiments between 9.4 and 44.8 sec. The rate of establishment of this form of CR varied with the length of delay; the longer the delay the greater number of trials required.

Delayed conditioned responses were always anticipatory, that is, the response occurred after a delay not quite equal to that used for conditioning. For example in the experiment from which the sample of Fig. 3 was taken conditioning trials were given with a delay of 29.8 sec. The CR occurred after a delay of 27 sec. and lasted until the sound was turned off. The accuracy of these conditioned delay periods has suggested further experiments on the nature of this process with particular reference to the estimation of time, to be reported later.

Extinction was not systematically studied but as many as 4 consecutive delayed CRs were obtained in some experiments with intervals as long as 30 seconds. It was found unnecessary to use Pavlov's method of conditioning first with short delays before extending them.

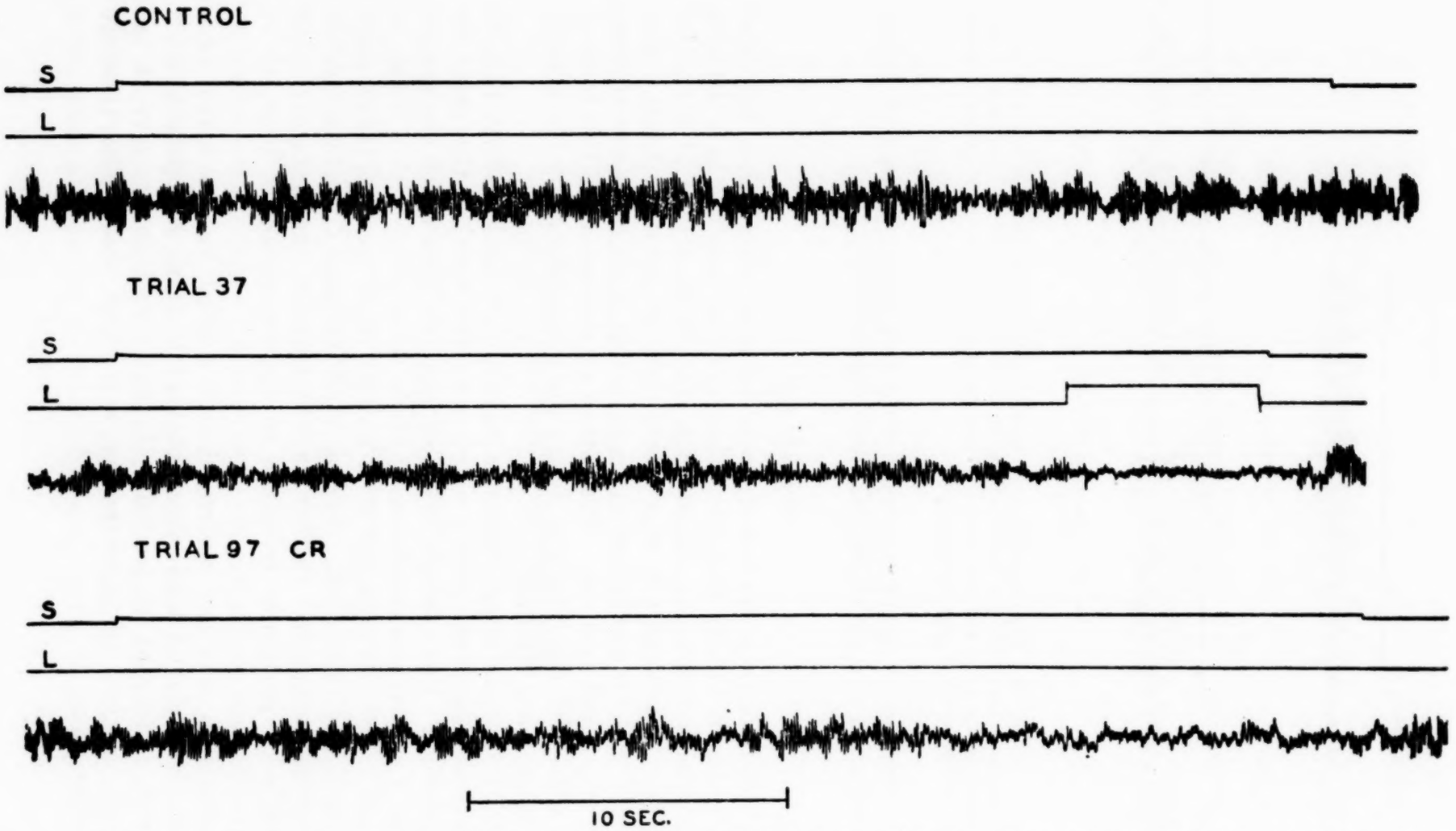


FIG. 3. *Delayed CR.* CONTROL shows no effect of long continuous sound stimulus before conditioning. TRIAL 37 was conditioning with delay of 30 sec. TRIAL 97 was test trial showing delayed conditioned blocking of alpha rhythm. It was anticipatory.

Trace CR

A trace CR was established in about 20 trials by stimulating first with a 5 sec. sound (700 cycles) then allowing a 9 to 10 sec. interval to elapse before the unconditioned light stimulus of 5 sec. duration. Controls showed no blocking of the alpha rhythm at any definite interval following a sound stimulus before conditioning. After conditioning, however, there was no immediate response to the sound but after it was turned off a clear block of the alpha rhythm occurred following a delay slightly less than that used for conditioning. The CR was anticipatory as for all such responses involving time. Accuracy in time was less for trace responses than for delayed responses, this being due to the greater prevalence of early responses (as short as one half the trace interval).

Sleep

In both the delayed and trace CR experiments an effect similar to Pavlov's induction of sleep was sometimes observed after 2 or 3 unreinforced trials. The alpha rhythm dropped out, delta waves greatly increased in amount, and the manual response could not be elicited. It was not possible, however, to find the subject asleep in the room on entering. In the 3 cases where this occurred 2 admitted the possibility of having dozed off and one denied it. Whether or not this phenomenon was simply drowsiness brought on by long confinement in a resting position, or due to 'irradiation of inhibition' cannot at this point be ascertained.

Differential CR

The conditioned blocking of the alpha rhythm to sound of a specific frequency (500 cycles) or a differential CR, was produced by pairing the light stimulus only with this frequency and not with others (400 to 475). A simple CR was first established as described above using only the 500 cycle sound. This sound was always reinforced by light while a 400 cycle sound was not. After about 70 trials from the beginning of conditioning an alpha block occurred to the 500 cycle sound alone but not to the 400 alone (Fig. 5). This differentiation is not due to extinction since, in testing, the 400 cycle stimulus was presented first, with no response, followed by the conditioned response to 500 cycles.

After establishing a relatively gross differentiation (100 cycles) the frequency of the non-reinforced sound was approximated more closely to 500 cycles (the reinforced stimulus). Differential CR was obtained for frequencies as close as 475 and 500 cycles per second.

Differential Delayed CR

A delayed CR to a specific tone (700 cycles) was established in about 100 trials. At first a delayed CR to a 700 cycle tone was established as described above. The delay interval was 9.4 sec. Then a 500 cycle sound stimulus was introduced but never followed

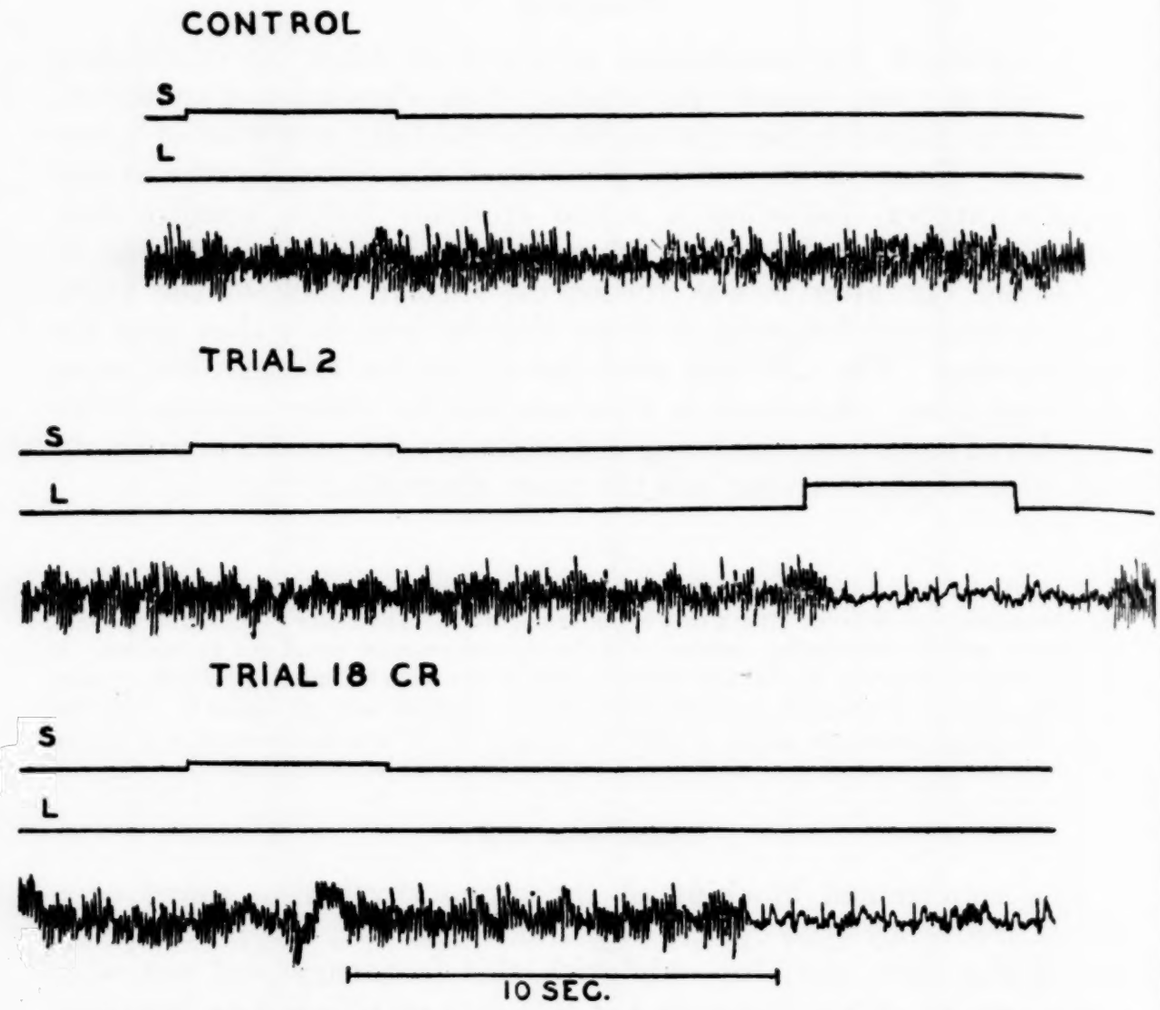


FIG. 4. *Trace CR.* After usual CONTROL, TRIAL 2 was conditioning trial with interval of 9.4 sec. between end of sound (*S*) and beginning of light (*L*). TRIAL 18 shows anticipatory CR to sound after delay of 8.4 sec.

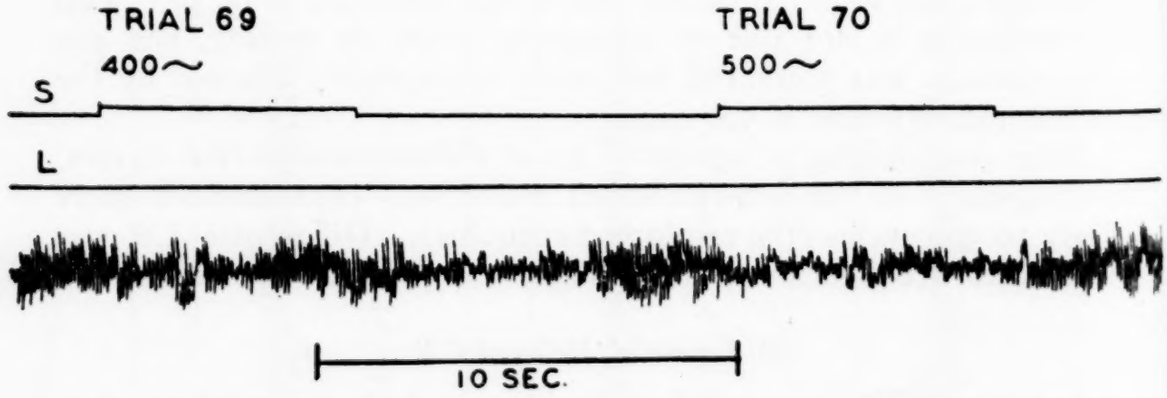


FIG. 5. *Differential CR.* Simple and differential CR to 500 cycle tone has been established (see text). TRIAL 69 shows absence of response to 400 cycles followed by response to 500 cycles in TRIAL 70.

by light while the 700 cycle stimulus was always followed by light after a definite interval. This type of conditioning was hard to establish, as shown by the number of trials necessary, but a clear differential response to the 700 cycle tone after a delay of 9.4 sec. was obtained (Fig. 6).

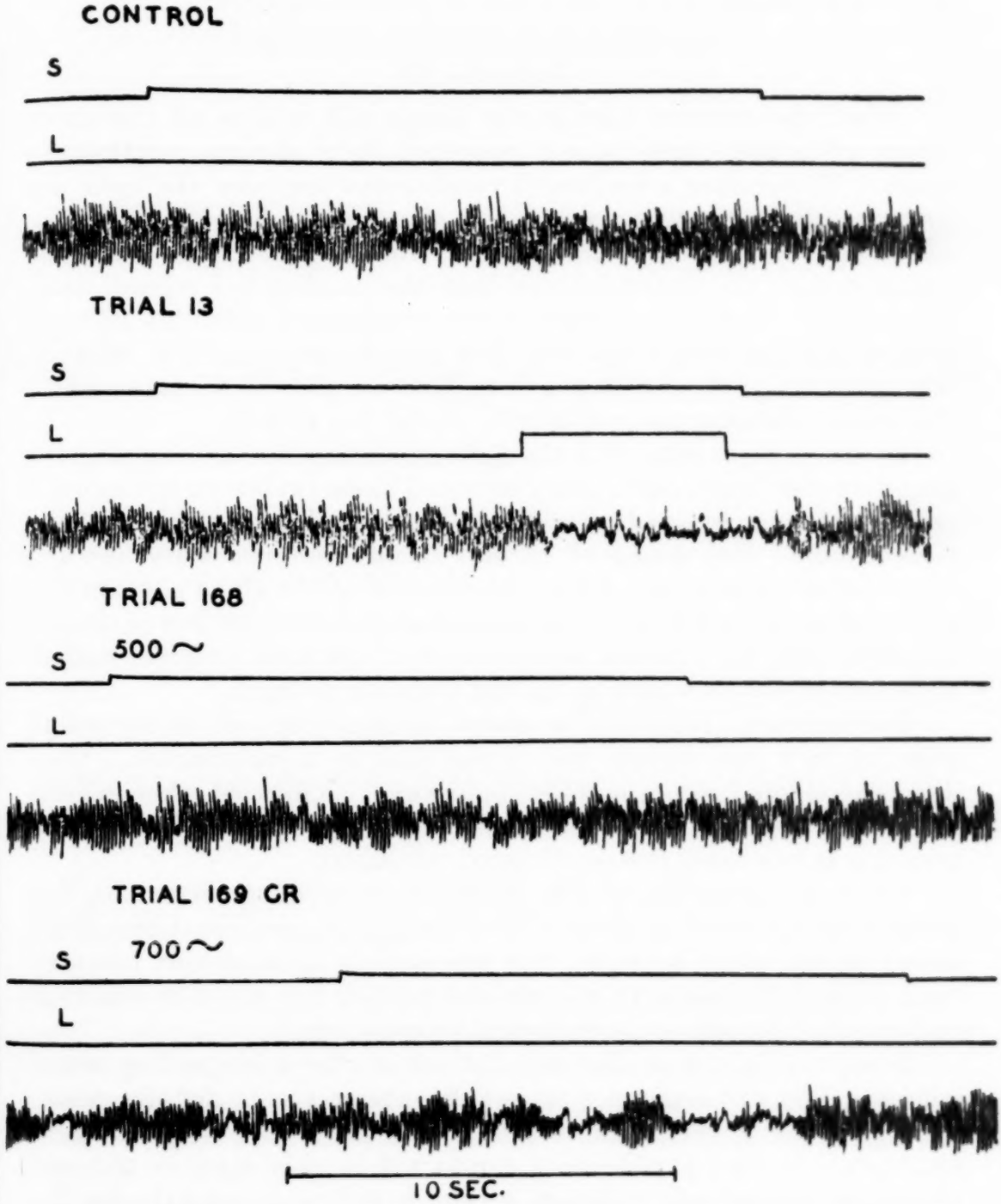


FIG. 6. *Differential Delayed CR.* CONTROL and delayed conditioning trial (TRIAL 13) are similar to those above except that 700 is then reinforced by light and 500 never paired with light. Test TRIAL 168 with 500 then caused no change in alpha waves (it did before differential conditioning) while 700 cycles in TRIAL 169 caused delayed blocking of alpha waves.

Before differential conditioning the 500 cycle tone produced immediately the same response as the conditioned 700 cycle tone. This was simple delayed conditioning to *sound*. There was no response to the 500 cycle stimulus after differentiation was completely established. The response to 500 was always tested before 700 to avoid the possible extinction effect of the reverse order.

Backward CR

It will be recalled that in the simple CR and in all the above forms of conditioning sound preceded light during conditioning trials. To produce a backward conditioned response the light was presented from 0.7 to 2.9 sec. before the sound. Since the duration of the light was, in these experiments, from 6 to 8 sec. and the sound about 5 sec., the unconditioned and the conditioned stimuli overlapped even though the onset of the conditioned stimulus followed that of the unconditioned. In two experiments the light stimulus was given for 5 sec. and then a 1 sec. interval allowed to elapse before the sound, allowing no overlapping of the two stimuli.

In the experiments with the light preceding but overlapping the sound a conditioned alpha block to sound alone (at least 2 consecutive responses) was obtained after about 100 paired presentations of the two stimuli. One hundred to 200 trials were necessary for 4–5 consecutive unreinforced CRs. Depression of the alpha rhythm was as complete in the CR as to the unconditioned stimulus but of shorter duration (Fig. 7). Latent periods were of the same order of magnitude for the CR to sound as for the response to light.

Subjects were requested to give a manual response to the sound stimulus in 7 experiments and to the light in 2 experiments. Conditioning seemed to occur with about equal facility whether manual response was to light or sound (possibly with less trials when manual response is to sound, the conditioned stimulus).

This type of backward CR, the light overlapping the sound, was usually extinguished in about 5 to 6 consecutive presentations of the sound unreinforced by light. In one subject spontaneous recovery took place following a 15 minute rest period, but the CR was then extinguished by only 2 unreinforced sound stimuli.

When the light preceded and did *not* overlap a succeeding sound stimulus, but was separated from it by about 1 sec., definite conditioning of the alpha block to sound was practically impossible to establish. In two experiments conducted in this manner 262 and 387 trials respectively failed to establish sufficient conditioning for 2 consecutive responses to sound alone. It should be noted that, in these experiments, the conditioned stimuli appeared during the

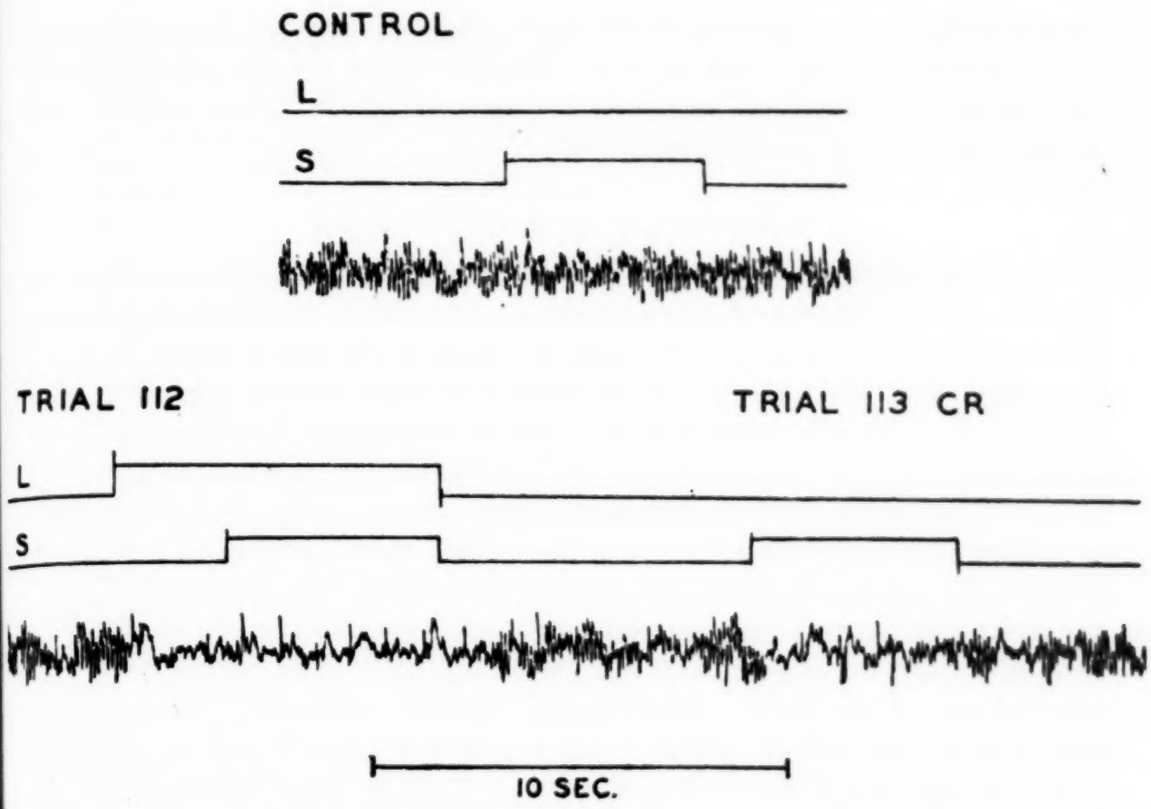


FIG. 7. *Backward CR.* Note inverted order of stimuli, light (*L*) preceeding sound (*S*) by 3.7 sec. in conditioning TRIAL 112. Test TRIAL 113 shows conditioned blocking of alpha rhythm to sound after backward conditioning.

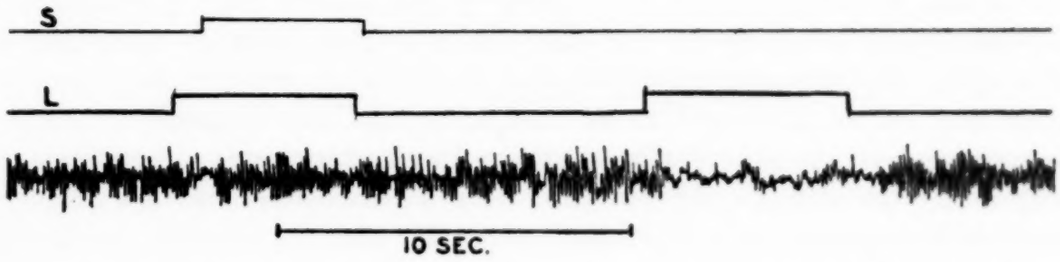


FIG. 8. *Counteraction Effect.* Sound (*S*) presented during a light stimulus (*L*) after backward conditioning caused a prompt return of the alpha rhythm. The succeeding light presented alone caused the usual blocking response.

presence of the alpha rhythm in the electroencephalogram. The sound was consequently associated in time with the *presence* rather than with the *absence* of alpha rhythm so that one might expect the conditioned sound to cause no depression or possibly an increase in alpha waves. That this may occur under certain conditions is shown in the following section.

Under the conditions of these experiments there were a few single depressions of the alpha rhythm to sound stimuli conditioned in this backward manner which may indicate certain excitatory processes of

visual stimulation lasting more than the one second interval used here between the light and sound. Further experiments are necessary to distinguish between persistent response of the sense organ and actual 'traces' in central neurones.

Counteraction of Sound on Light

During the course of backward conditioning with overlapping stimuli it was observed that, after at least five conditioning trials, the introduction of a sound stimulus during an alpha block to light produced a sudden return of the alpha rhythm before the light was turned off. This counteraction effect of sound on light is similar to that described by Williams (**30**) as 'facilitation of the alpha rhythm.' It could be produced in certain subjects more easily than in others.

After prolonged conditioning the sound alone produced a depression of the alpha rhythm, but when the sound was introduced after the light was turned on it caused a prompt *return* of the alpha rhythm. It seems that we are dealing here with simultaneous facilitation and inhibition. The same conditioned sound stimulus produced a blocking of the alpha rhythm when alpha was present but an increase in alpha rhythm when it was absent. For the establishment of the counteraction effect, several trials are necessary as for conditioning.

Discussion

It has been shown in the above experiments that alteration of the electrical activity of the occipital lobes in man as manifest in the alpha rhythm and its depression or blocking with visual stimulation may be conditioned to an auditory stimulus in such a manner as to demonstrate practically all of the Pavlovian types of conditioned response. In spite of the fact that we are dealing here with a directly recorded response of the higher centres, not necessarily involving peripheral effector systems, the alpha block conditioned to sound or to time shows the characteristics of a Skinner (**26**) Type II conditioned response. It is, however, very unstable: appearing with relatively little practice and showing rapid extinction. Some of this instability may be due to the fact that there was practically no motivation and the entire conditioning took place in one sitting. Further experiments with more prolonged training periods and stronger motivation would be necessary to examine the possibility of establishing a more stable response.

The success here obtained with backward conditioning would seem to indicate the value of the electroencephalograph as a sensitive instrument for the study of theoretical problems in conditioning. Pavlov's early view was that conditioning is impossible unless the

conditioned stimulus precedes the unconditioned one, but in the Croonian Lecture (**23**) he stated:

> if the stimulus is introduced after the beginning of the activity, then, although as our present experiments seem to show, a conditioned reflex may also develop, it is insignificant and evanescent; on continuing the procedure, the stimulus, which in this connection we term the neutral agent, becomes inhibitory.

Switzer (**27**) obtained backward CR of the eyewink in very few trials, but Porter (**24**) was unable to produce it in 65 trials. Cason (**6**) using a completely passive method, was also unsuccessful. Bernstein (**3**) found very few backward CRs for hand withdrawal, as did also Wolfle (**31**). Woodworth (**32**) states:

> It is too early to assume a categorical conclusion on backward conditioning, but the concept is certainly not a safe one to assume in explaining the other phenomena of learning.

In reviewing the work on backward association Guthrie (**11**) expresses the view that backward conditioning is possible if the unconditioned response and the conditioned stimulus overlap. Since these conditions are usually difficult to produce experimentally, backward conditioning is ordinarily relatively unsuccessful. With the alpha rhythm block as a response it is possible to verify Guthrie's theory and to show that backward conditioning can be produced in about 10 times the number of trials necessary for simple CR if the stimuli overlap, but not with separated stimuli.

The counteraction of sound on light in these backward conditioning experiments may be analogous to Pavlov's 'inhibitory stimulus.' In the latter case salivation is arrested by an extraneous 'distracting' stimulus. In our experiments the arrest of the alpha rhythm during visual stimulation is released by an extraneous auditory stimulus but only *after conditioning*.

The counteraction effect apparently develops simultaneously with the conditioned blocking effect even though the one causes a return of the alpha rhythm and the other its disappearance. In our experiments the counteraction effect appeared earlier in the conditioning series than did the conditioned blocking reaction when the light preceded but overlapped the sound, but the two processes seemed to be developing together. If the blocking of the alpha rhythm by visual stimuli be considered due to desynchronization of the 'spontaneous' rhythm of the neurones involved by excitation from incoming afferent stimuli (Jasper, **15**) (Bremer, **5**) the return of the alpha rhythm by sound might be considered a form of 'inhibition.' Therefore, facilitation (conditioning) and inhibition seem to develop together in conditioning, a concept suggested by Hull (**14**) and recently given experimental verification and exact mathematical treatment by Graham and Gagné (**10**).

There is an increasing body of evidence to show that positive conditioning is primarily a facilitation process. Gerard, Marshall and Saul (**9**) have shown that the electrical response to sound, which is recorded from an auditory nucleus in the mid-brain, is increased by a simultaneous visual stimulus. Martino and Fulchignoni (20) trained a dog to give a conditioned blink response of the left eyelid to red light and of the right eyelid to violet light. On strychninization of the right occipital lobe red light produced clonic movements of the left eyelid followed by generalized epileptoid seizures. Violet light had no such effect. Strychninization of the left occipital lobe enabled the violet light to produce the same result in the left eyelid while red light was ineffective. Hilden (**12**) in an electromyographic study showed that conditioned hand withdrawal was gradually built up. First only a few motor units were seen to respond before sufficient conditioning for a visible movement.

Some form of facilitation process must also be operating when an auditory stimulus can be conditioned to produce a change in the electrical activity of the occipital lobes indistinguishable from that caused by the unconditioned visual stimulus. Repeated paired presentations of sound and light gradually lower the threshold of certain preexisting synaptic pathways, probably mid-brain, so that auditory stimuli temporarily become effective in desynchronization of the occipital alpha rhythm.

Conditioning studies of the electrical activity of the higher centres are not necessarily identified with those based upon effector responses. Many changes occur in the cortex which are not reflected in peripheral neurones as shown by Adrian and Moruzzi (**2**), Moruzzi (**22**), and Jasper and Andrews (**16**). A most striking demonstration is provided by epileptic discharges of the cortex, which when of moderate amplitude, produce no detectable motor response. However, further increase in cortical discharge is sufficient to cause adequate summation for excitation of motor neurones. Thus cortical activity as directly recorded is related to the 'stimulus-response' system, and principles of conditioning derived from brain potential studies may be applied to general problems of conditioning.

Advantages of electroencephalographic studies of conditioning are principally the facility and rapidity with which various types of CR may be demonstrated in man and its relative independence of voluntary influence. The chief disadvantage is the instability of the CR. Also unless a subject has an almost continuous alpha rhythm which is free from prolonged 'spontaneous' variations, and which responds clearly to visual stimuli, unequivocal conditioned responses cannot be obtained.

Summary

1. The disappearance of the occipital alpha rhythm in man was conditioned to auditory stimuli in the classical Pavlovian manner. The following types of conditioned response were established: simple, cyclic, delayed, trace, differential, differential delayed, and backward. In some cases extinction and spontaneous recovery were shown.

2. After several trials with the backward conditioning technique a sound stimulus reestablished the alpha rhythm if introduced during its depression by light (counteraction effect). With further conditioning, the sound alone produced blocking of the alpha rhythm. This suggests simultaneous 'facilitation' and 'inhibition' processes during conditioning.

3. A state resembling sleep was produced during conditioning of long delay and trace intervals, that is, slow waves appeared in the electroencephalogram and the subjects failed to give the usual manual response.

4. The relation of electroencephalographic studies to general problems of conditioning was discussed.

(Manuscript received October 19, 1940)

References

1. Adrian, E. D., and Matthews, B. H. C., The Berger Rhythm; potential changes from the occipital lobes in man, *Brain*, 1934, **57**, 355–385.
2. Adrian, E. D., and Moruzzi, G., Impulses in the pyramidal tract, *J. Physiol.*, 1939, **97**, 153–199.
3. Bernstein, A. L., Temporal factors in the formation of conditioned eyelid reactions in human subjects, *J. genet. Psychol.*, 1934, **10**, 173–197.
4. Bogoslovski, A. I., An attempt at creating sensory conditioned reflexes in humans, *J. exp. Psychol.*, 1937, **21**, 403–422.
5. Bremer, F., Parenté des diverses ondes électriques de l'écorce cérébrale, *C. R. de la Soc. de biol.*, 1938, **128**, 544–550.
6. Cason, H., Backward conditioned eyelid reactions, *J. exp. Psychol.*, 1935, **18**, 599–611.
7. Cruikshank, R. M., Human occipital brain potentials as affected by intensity-duration variables of visual stimulation, *J. exp. Psychol.*, 1937, **21**, 625–641.
8. Durup, G., and Fessard, A., L'électrencéphalogramme de L'homme, *L'année Psychol.*, 1935, **36**, 1–32.
9. Gerard, R. W., Marshall, W. H., and Saul, L., Electrical activity of the cat's brain, *Arch. Neurol. Psychiat.*, 1936, **36**, 675–738.
10. Graham, C. H., and Gagné, R. M., The acquisition, extinction and spontaneous recovery of a conditioned operant response, *J. exp. Psychol.*, 1940, **26**, 251–280.
11. Guthrie, E. R., Association as a function of time interval, *Psychol. Rev.*, 1933, **40**, 355–367.
12. Hilden, A. H., An action current study of the conditioned hand withdrawal, *Psychol. Mon.*, 1937, **49**, 172–204.
13. Hilgard, E. R., and Marquis, D. G., *Conditioning and learning*, N. Y.: D. Appleton-Century Co., 1940.
14. Hull, C., Mind, mechanism, and adaptive behavior, *Psychol. Rev.*, 1937, **44**, 1–32.
15. Jasper, H. H., Cortical excitatory state and synchronism in the control of bioelectric autonomous rhythms, *Cold Spring Harbour Symposium, Quant. Biol.*, 1936, **4**, 320–338.
16. Jasper, H. H., and Andrews, H. L., Brain potentials and voluntary muscle activity in man, *J. Neurophysiol.*, 1938, **1**, 87–100.

17. JASPER, H. H., AND CRUIKSHANK, R. M., Electroencephalography II: Visual stimulation and the after-image as affecting the occipital alpha rhythm, *J. gen. Psychol.*, 1937, 17, 29–48.
18. LOOMIS, A. L., HARVEY, E. N., AND HOBART, G. A., Electrical potentials of the human brain, *J. exp. Psychol.*, 1936, **19**, 249–279.
19. LOOMIS, A. L., HARVEY, E. N., AND HOBART, G. A., Brain potentials during hypnosis, *Science*, 1936, **83**, 239–241.
20. MARTINO, G., AND FULCHIGNONI, E., Uber die Bedeutung bedingter Reize (fur den Bahnungsprozess) bei der durch stychninisierung der occipitalen Rinde reflektorisch erzeugten Epilepsie, *Pflüg. Arch. ges. Physiol.*, 1938, **240**, 212–220.
21. MILLER, J., AND COLE, E., The influence of a voluntary reaction upon the development and the extinction of the conditioned eyelid reaction, *J. genet. Psychol.*, 1936, **48**, 405–440.
22. MORUZZI, G., Contribution a l'électrophysiologie du cortex moteur: facilitation, afterdischarge et épilepsie corticales, *Arch. internat. de Physiol.*, 1939, **49**, 33–100.
23. PAVLOV, I. P., *Lectures on conditioned reflexes*, Tr. by W. H. Gantt, N. Y. Int. Publishers, 1928.
24. PORTER, J. M., JR., Backward conditioning of the eye-lid response, *J. exp. Psychol.*, 1938, **23**, 40–410.
25. SHURRAGER, P. S., AND CULLER, E. A., Conditioning in the spinal dog, *J. exp. Psychol.*, 1940, **26**, 133–159.
26. SKINNER, B. F., Two types of conditioned reflex and a pseudo type, *J. gen. Psychol.*, 1935, **12**, 66–77.
27. SWITZER, C. A., Backward conditioning of the lid reflex, *J. exp. Psychol.*, 1930, **13**, 76–97.
28. TRAVIS, L. E., AND EGAN, J. P., Conditioning of the electrical response of the cortex, *J. exp. Psychol.*, 1938, **22**, 524–531.
29. WALTER, W. G., The technique and application of electroencephalography, *J. Neurol. and Psychiat.*, 1938, 359–385.
30. WILLIAMS, A. C., Some psychological correlates of the electroencephalogram, *Arch. Psychol.*, 1939, pp. 48.
31. WOLFLE, H. M., Conditioning as a function of the interval between the conditioned and the original stimulus, *J. gen. Psychol.*, 1932, **7**, 80–103.
32. WOODWORTH, R. S., *Experimental Psychology*, N. Y.: Henry Holt & Co., pp. 92–123, 1938.

THE RELATIONSHIP BETWEEN PATTERNS OF ERGOGRAPH DECREMENT AND DECREMENT IN OTHER TASKS [1]

BY B. R. BUGELSKI

University of Toledo

In a previous study (1) it was shown that individuals working in a Mosso ergograph tend to produce patterns of decrement peculiar to themselves. The significance of this consistency, however, has not yet been established, although numerous attempts have been made to relate the individual differences in patterns of ergograph decrement to other personality features. Marks (7) and Yochelson (15) have reviewed the literature on individual differences in the pattern of work decrement. Both reviewers find the attempts to correlate ergographic results with different typological theories uncritical in method, and unsuccessful or unconvincing in results. Enke (2), for example, found but slight differences between ergographic records produced by individuals of different body types as described by Kretschmer. Lehman (5) described three energy types: energetic, anergetic, and fatiguable. These descriptions were based on the examination of ergographic records without an attempt to validate the types against any other criteria. More recently Koch (4) has emphasized differences in work types, based on observation of the working rhythms of agricultural workers. Koch did not adapt the ergographic technique to the study of work types but his suggestions have been followed by recent Italian students of ergography (9), (12). Yochelson found no relation between ergographic records and types of psychosis (15). Marks found no relation between work curve types and body build (7).

The failure of these studies to demonstrate reliable relationships between the results of ergography and the particular typology which interested the investigators may have been due to a number of causes: (1) Individual differences may be too great to reveal differences between groups of any kind; especially when the subjects studied are divided into rigid types; (2) the particular physical and psychological types employed may have genuine significance but may be irrelevant to the factors determining the pattern of work decrement. In attempting to explain individual differences Mosso (10)

[1] This is the second of a series of three articles dealing with factors responsible for individua differences in the pattern of work decrement in ergographic work. The three articles were presented in partial fulfillment of the requirements for the degree of Doctor of Philosophy at Yale University in 1938. This experiment was carried out in the laboratory of the Department of Psychology, Antioch College.

spoke of individuals who are 'more persevering.' These terms are essentially descriptive of attitudes toward work, and a psychological classification of individuals in terms of attitudes and characteristic reactions to work situations might show a closer relation between ergographic work and the characteristics of the individual.

Recent studies in the psychology of work, especially those of Manzer (**6**) and Yochelson (**15**), have demonstrated the importance of the subject's attitudes toward the work situation in determining work output. The emphasis on energy types and work types in European psychology suggests that these attitudes may be relatively constant features of individual personalities and that these attitudes determine the way in which an individual will adapt himself to any situation involving routine muscular work. In emphasizing the integrated nature of the organism, Robinson (**13**, p. 583) said of work curves: "One might almost say that the curve is a personality trait." Such a statement, when considered in the light of the above mentioned psychological influences on work, sets the specific hypothesis of this study: individual differences in patterns of decrement in the ergograph may be, to some degree, expressions of an individual's characteristic way of reacting to situations involving routine muscular work. By the phrase 'characteristic way of reacting' is meant the whole complex of attitudes, sets, expectations, and habits which the individual carries with him from one work situation to another. The possibility of testing the hypothesis rests upon the assumption that these characteristic ways of reacting are general enough to transfer to the simple experimental situation typified by the ergograph.

An adequate test of the proposed hypothesis could be made if subjects could be obtained whose characteristic ways of reacting to routine work situations are known. Such stereotypes as the 'plodder,' the 'go-getter,' the lazy, shiftless person, etc. might be used if some technique were available by which they could be adequately selected in sufficient numbers. Such a technique, however, is not available at present. Another possible test of the hypothesis was undertaken in the present study; namely, to determine empirically how various subjects work at several routine tasks and to compare these performances with their ergograms. In order to do this it was first necessary to select a number of suitable tasks. The field of possible choices was limited to such tasks as would produce a decrement with continuous work; this restriction eliminated tasks in which a learning or practice effect was present. Most tasks, however, offer opportunities for improvement in technique, short-cuts, substitution of muscle groups, etc. which enable a subject to continue almost indefinitely at the same pace, or even improve. Such tasks as card-sorting, packing blocks in boxes, placing pegs in a peg-board, mental

addition, and reciting the letters *a* and *b* in random order were tried on a number of subjects; none of these tasks proved satisfactory because even after periods up to two hours the subjects were still performing at the same rate or better than when they had started.

After further preliminary experimentation three tasks were selected which did show a fairly pronounced decrement within as little as five and ten minutes of work. These tasks were: (1) writing alternately the letters *p* and *q*, (2) turning the crank of a hand drill, and (3) pressing the keys of a mechanical counter against spring resistances. The tasks selected provided a desirable variety which recommended them for study; the task of pressing keys with the fingers was in direct contrast to the ergograph task of pulling; the turning of the drill crank tested the wrist, arm, and shoulder and involved a good deal of muscular coördination; the writing task was largely one of coördination. The drill task was performed with a series of successive rests and in this respect approximated working conditions of a more general nature. It was thought that these tasks furnish sufficient variety to serve as an indication of the individual's performance in other tasks of a routine nature as demanded by the hypothesis. Comparisons of ergograms with patterns of decrement in these tasks would afford an opportunity to discover whether the ergograph record was an indicator, in miniature, of a more general personality trait, or just one unrelated feature of an individual. In addition, comparisons of successive performances of each task would reveal possible similarities in decrement patterns of the individual tasks, regardless of the nature of their relationship with each other.

Apparatus and Procedure

Each subject performed each of four tasks on two successive occasions. A preliminary practice period preceded the first recording of decrement in any task. The four tasks and apparatus involved will be discussed separately.

Task I. *Writing.* The subject was provided with several sheets of paper, 13 × 8½ inches, and several sharpened pencils. He was directed to write the letters *p* and *q* alternately as rapidly as possible and without pause for rest. After each 30 seconds of writing the experimenter pronounced the word 'now' which was a signal for the subject to draw a diagonal line following the last letter he had written and to continue anew. The work period lasted for 15 minutes and resulted in 30 work units in terms of number of letters per 30 seconds. It was later discovered that whatever decrement was found would take place within 10 minutes[2] and so the last five minutes of work were not considered in the results.

Task II. *Rotary Drill.* The Miles Rotary Drill (8) was adapted as a device to measure decrement. This drill is provided with a counter which registers the number of turns made at the crank. The subject placed the drill point in a shallow pit in a hard rubber block and at a signal began to turn the crank as rapidly as possible. After 25 seconds of work he was told to stop and rest for five seconds during which time the counter was read; following the five-second rest the subject again turned the crank as quickly as possible for another 25 seconds. This procedure of alternate work and rest was continued for 10 minutes and gave a record of the amount of work done in each of 20 one-half minute periods. Since each revolution of the crank

[2] This was reported also by Robinson (15, p. 610).

was registered as an increase of 4 units on the counter, the readings ran into hundreds; for convenience of treatment all readings were divided by 10 and corrected to the nearest whole number.

Task III. *Counter.* A counting device consisting of a series of five keys was adapted to serve as an ergometer.[3] The keys were mounted on springs of a fairly strong tension. Each pressure on a key resulted in the appearance of a number in a slot above the keys. The device resembled an ordinary cash-register in miniature. The counter was mounted on a board and clamped to a table. An athletic wrist-band was used to secure the subject's arm and wrist which lay flat with the top of the board. The subject was instructed to press two of the keys alternately with the first and second fingers as rapidly as possible, using only the fingers, and to continue doing so until told to stop. The experimenter then started a stop-watch and recorded the time at which the subject registered 20 pressures; this was continued until a total of 400 pressures had been made, or 20 series of 20 pressures. Each work session lasted from 4 to 5 minutes.

Task IV. *Ergograph.* A finger ergograph of the Mosso type (1) was used to measure decrement in the isolated finger. The ergographs were traced on waxed paper. Male subjects worked with a 4 kilogram weight; female subjects with a 3 kilogram weight. The subjects were instructed to bend the finger back as far as possible in time with a metronome and to continue pulling until they could no longer raise the weight.

It will be noted that each of the first three tasks involved work at maximum speed while the ergographic work was timed with a netronome. This procedure was necessary because no decrement would result in the first three tasks unless speed was demanded. The ergographic work could have been done at maximum speed also but it was decided to use the metronome for two reasons: (1) it would be more comparable to earlier results on which various claims had been based; (2) Yochelson (15) found no differences in patterns of decrement when subjects worked at maximum speed.

The Subjects.—Forty college students, 16 women and 24 men, served as subjects. They ranged in age from 17 years to 23 years, and in college standing from freshmen to seniors. The subjects volunteered their services and were not paid. The subjects evinced a strong interest in the experimental work although they remained ignorant of the purpose of the study. Prompt appearance and interest were taken to indicate fairly strong motivation in the tasks. In all cases subjects were encouraged at the beginning of each task to do their best. No additional attempts were made to motivate the subjects.

In most cases the subjects reported for work on two successive days. A preliminary practice period preceded the recording of data in any task. Each task was performed once on each day and a 10 minute rest was introduced between tests. The order of the tasks was varied from subject to subject to avoid any cumulative effect on the results of any one task.

The curves of decrement for each subject were plotted on squared paper (four squares to the inch) cut to uniform 5 × 8 inches size. All lines were drawn in heavily with a soft pencil and labelled on the reverse side with the subject's name and number of the performance, *i.e.*, first or second. To avoid any possible cues due to similarity of pencil stroke, etc. the curves were drawn in random order so that any tendency to make the two curves of any one subject similar in some irrelevant respects was minimized. The original ergograph curves were mounted on plain 5 × 8 cards.[4]

Results

In order to evaluate the hypothesis on which this study was based it was necessary to analyze the data obtained in ways which would provide answers to two questions; (1) do individuals tend to reach

[3] This device was designed by Pressey (13) and is manufactured by the W. M. Welch Scientific Company, Chicago, Illinois.

[4] The ergograph curves were also reduced to 20 points (medians of each 20th of the curve) and graphed similarly. This was done to control the factor of different length of curves produced by the same subjects. The curves plotted from these medians resembled the original ergographs closely enough that two college instructors were able to match the curves in groups of five in all but three cases which were interchanged because of similarity to each other. It was later found that this procedure was unnecessary as the results were not influenced materially.

decrement in the same way in a repeated performance of the same task? and (2) is there any similarity between the patterns of decrement an individual produces in different tasks? Four methods for treating the data were devised: (1) judges attempted to match the work curves made by the same individuals; (2) the points at which the level of performance fell below certain values were correlated; (3) the percentages of decrement undergone in the various tasks were correlated; and (4) average curves were constructed for men and women to detect possible sex differences. The methods of treatment and the results obtained from each method will be described separately.

1. *Matching*

Five college instructors attempted to match the work curves made by each individual in the four tasks. The work of judging was divided into two sessions; in the first session the judges compared curves produced in the same task, and in the second session they compared curves produced in different tasks. The first sets of judgments were made to determine the degree of consistency of decrement pattern at any one task. The following procedure was employed:

A. Matching for Consistency in the Same Task.—The 40 work curves produced in the first work session at one task, *e.g.*, the ergograph, were distributed by the experimenter in groups of five, face upward, on eight tables; the distribution was random. The experimenter then handed the five work curves produced in the second work session at the same task by the same subjects whose curves were on the first table to a judge and instructed him as follows: Place each of the curves in your hand next to the curve on the table that most closely resembles it in pattern of decrement. Consider such things as the amount of work done before any large drop, the nature of the drop: is it gradual or sudden, convex or concave? and the amount of work done after the drop. In short, place those curves which look most alike together. You can change your opinion as often as you like. The same procedure was repeated for the remaining tables. When a judge finished comparing curves made in one task, he repeated the above procedure for the other three tasks.

The judges reported little or no indecision about the comparisons and were quite satisfied that the curves placed together really did resemble each other except in a few instances where they did not feel quite certain about some of the curves.

On the whole the judges made relatively few errors in matching the curves made at any one task. It was noticed that in most cases when a curve was incorrectly placed, *e.g.*, the curve made by Subject A was placed with that of Subject B, that the error would be repeated; that is, the curve of Subject B would then be placed with that of

Subject A, instead of with any of the other three curves. The two curves made by two subjects might be so much alike that there was as much reason for matching one with the other as with its actual mate. These reversals were due to a similarity between the mates; for this reason they are not considered as actual errors although they are treated separately. Had the curves been selected in advance so that individuals who worked in the same ways were not placed in the same group of five such reversals would be more infrequent; such arbitrary selection, however, would be open to the criticism that the curves were matched not on similarity to each other but on lack of similarity to any of the others.

The judges who spent most time on the matching scored relatively more direct hits—if two curves that had been reversed by the judges were placed properly, the judges could see the possible reasons—a feature or two which they had overlooked or under-rated in the judging. Knowing that two curves were made by a certain individual apparently makes the observer see resemblances between the curves that he could not see previously or which he did not think were sufficient to demand matching of the curves. For this reason a number of samples of curves made by the same individuals are included (see Figs. 1–3). It is significant in this connection that the early work on the consistency of ergographic performance was usually treated in this way; that is, the curves made by the same individual would be presented together and would look alike to those who cared to see resemblances between them. The matching technique counteracts this subjective interpretation.

The number of correct and reversed matchings made by each judge for each set of work curves is presented in Table I-*A*. The actual scores confirm the opinions of the judges. By chance alone each judge should have matched at least one pair of curves correctly at each table, or 8 pairs correctly of the 40 possible pairs. The average number of direct matchings for all tasks was 23.80, almost three times the chance expectation, and, by the ordinary $)\overline{npq}$ formula, highly reliable (critical ratio: 6.24).[5] The highest number of direct matchings was secured in the Counter task; the Ergograph curves were matched almost equally well, while the Drill and Writing tasks proved least reliable though still well above the chance scores. When the reversals are added to the correct matchings, the number of matchings is 34.80 out of a possible 40 (critical ratio: 8.58). The

[5] This formula is not strictly applicable to the present data because the judgments were not independent events as demanded by the formula. The chance expectation is nevertheless 1 out of 5. Errors resulting from the use of the formula do not materially affect the conclusions because of the wide differences from chance results. The critical ratios are given merely for comparative purposes.

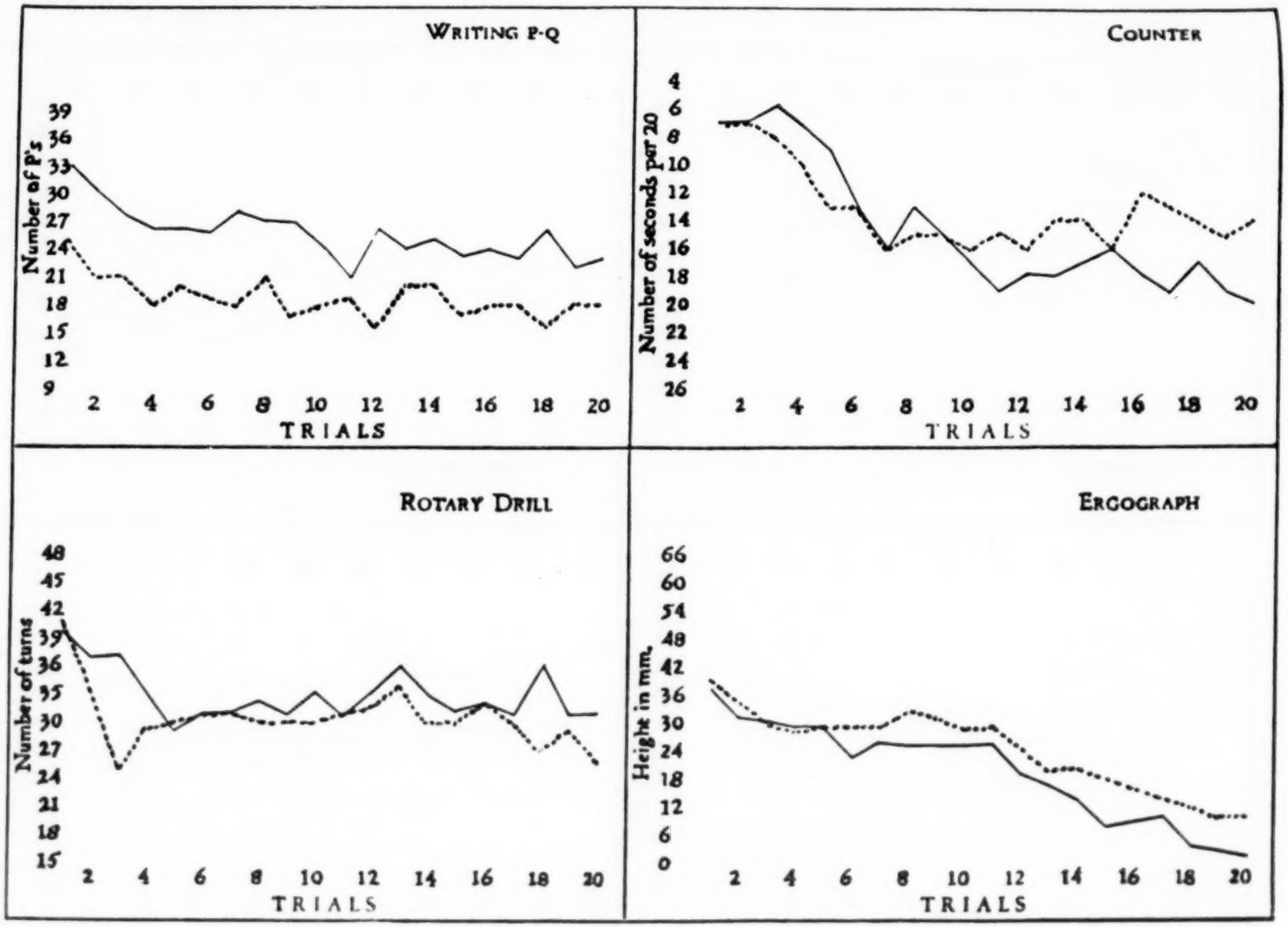


FIG. 1. Sample work curves of one subject (male) in four tasks. First work period ..... Second work period ———.

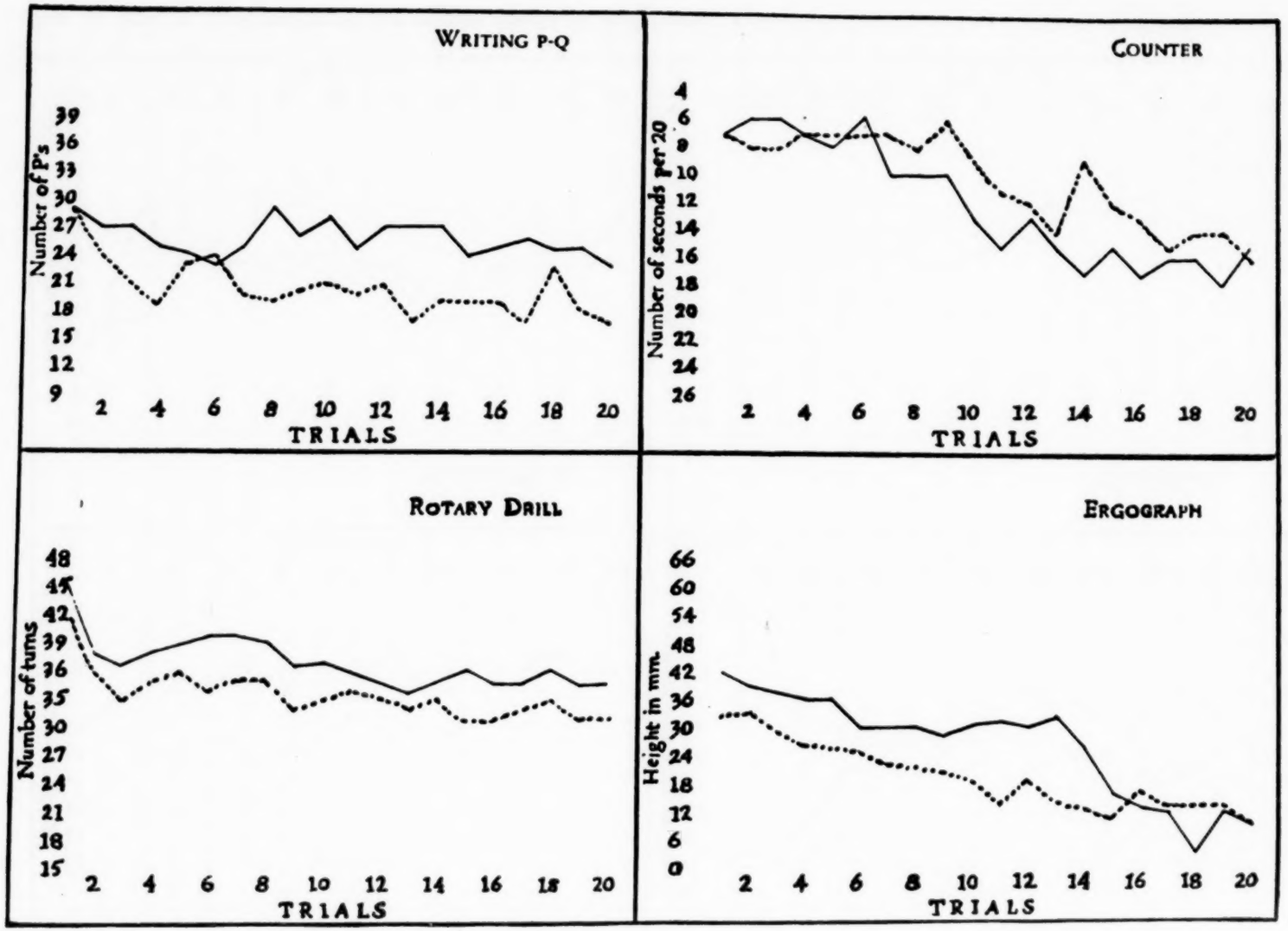


FIG. 2. Sample work curves of one subject (male) in four tasks. First work period ..... Second work period ———.

WRITING P-Q
COUNTER

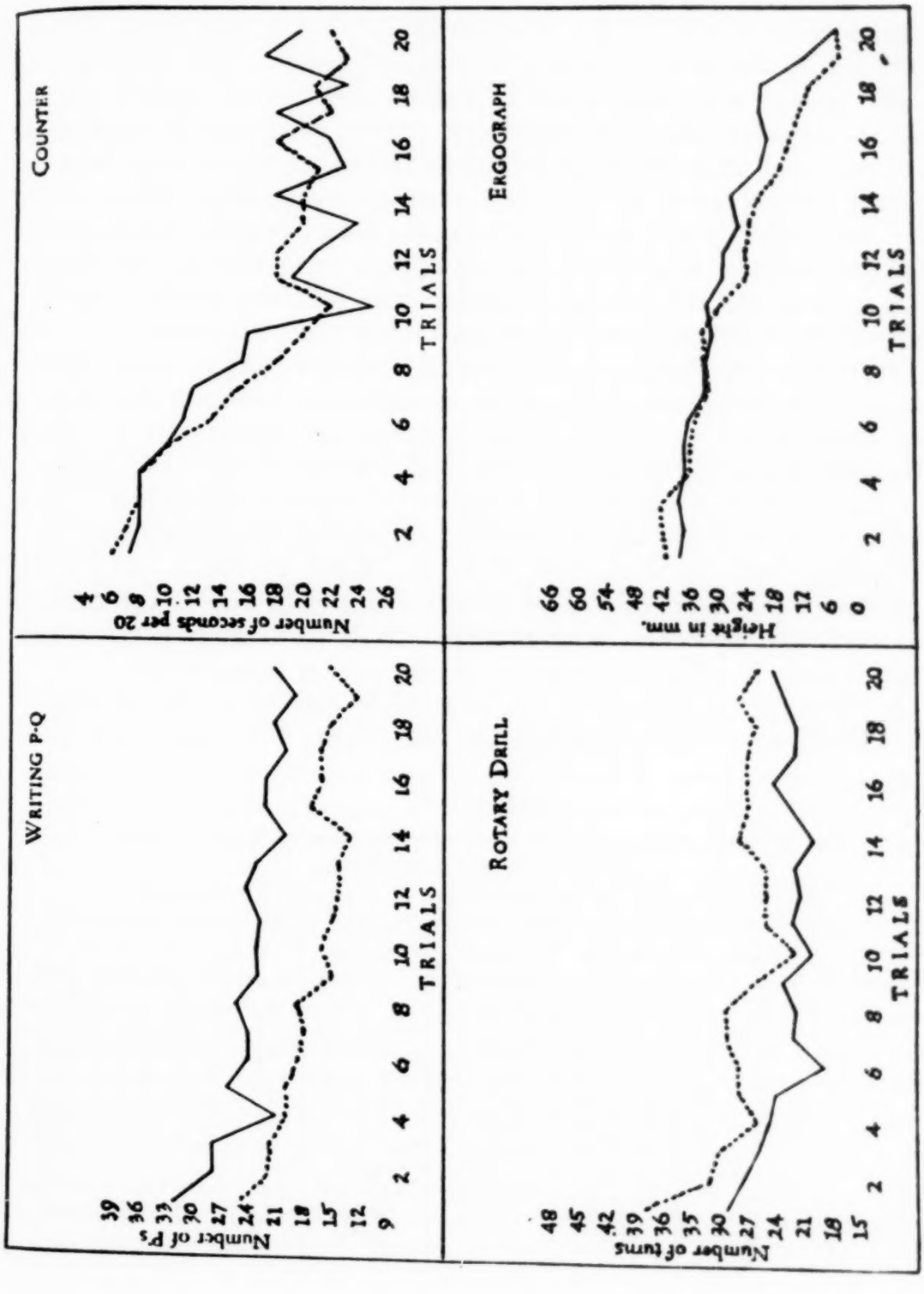


FIG. 3. Sample work curves of one subject (female) in four tasks. First work period ..... Second work period ——.

chance expectation of making either a correct matching or a reversal is, of course, higher (approximately 16 out of 40).

B. Matching for Consistency in Different Tasks.—In the second judging session the judges attempted to match the work curves produced by the same subjects in different tasks. The instructions to the judges were the same as before and the procedure varied only in the fact that now the work curves produced in each task were matched with those produced in the other three tasks instead of with curves made in the same task as previously. Since there were four tasks, it was necessary to make six inter-task comparisons. In these judging sessions the work curves produced in the second work sessions at each task were used because of their greater freedom from errors of unfamiliarity with apparatus and procedure.

In these inter-task comparisons all of the judges were of the opinion that there was little or no resemblance between the curves they were asked to judge; these opinions are borne out by their scores which are presented in Table I-*B*. None of the combinations of tasks showed a significant number of correct matchings. The combination with the highest number of correct matchings was that of Writing-Drill (critical ratio = 1.66). Both of these tasks were 10 minute tasks involving more coordination than any of the others. This criterion, however, does not lend itself to arranging the other combinations in a logical order as no such order is apparent.

A noteworthy feature of the matching results is the relatively high reliability of the ergograph curves (Table I-*A*) and their very

TABLE I-*A*

THE NUMBER OF CORRECT AND REVERSED MATCHES OF WORK CURVES PRODUCED IN THE SAME TASK

The four tasks were matched separately. C = correct; R = reversed

Judge	Ergograph		Writing		Drill		Counter		Total		Ave. C	Ave. C plus R
	C	R	C	R	C	R	C	R	C	R		
T. R.	23	14	18	18	18	12	28	4	84	48	21.00	33.00
E. F.	35	2	23	14	28	8	28	8	114	32	28.50	36.50
C. L.	20	16	15	22	25	6	25	12	85	56	21.25	35.25
P. T.	28	6	15	20	24	8	31	6	98	40	24.50	34.50
S. V.	26	8	17	18	25	8	37	10	95	44	23.75	34.75
Totals	132	46	85	92	120	42	139	40	476	220	119.80	174.00
Ave. C	26.40		17.00		24.00		27.80				23.80	34.80
Ave. C R	35.60		35.40		32.40		35.80					

low degree of correspondence with curves made at other tasks (Table I-*B*). The scores in the latter table are just about what would be expected simply through chance and indicate that the

TABLE 1-*B*

THE NUMBER OF CORRECT AND REVERSED MATCHES OF WORK CURVES PRODUCED IN DIFFERENT TASKS

The second curves produced by each subject in the four tasks were matched with each other.

Judge	Erg. & Writ.		Erg. & Drill		Erg. & Count.		Writ. & Drill		Writ. & Count.		Drill & Count.		Total		Ave. C	Ave. C plus R
	C	R	C	R	C	R	C	R	C	R	C	R	C	R		
T. R....	5	2	11	12	7	12	16	8	13	0	11	10	63	44	10.50	17.83
E. F.....	9	2	4	8	8	2	15	12	16	6	7	4	59	34	9.83	15.50
C. L.....	4	10	12	8	7	20	8	6	7	4	5	4	43	52	7.17	15.83
P. T.....	11	6	17	12	5	2	9	22	10	16	14	8	66	66	11.00	22.00
S. V.....	3	2	9	4	13	12	13	10	13	10	7	4	58	42	9.67	16.67
Totals...	32	22	53	44	40	48	61	58	59	36	44	30	289	238	48.17	105.40
Ave. C..	6.40		10.60		8.00		12.20		11.80		8.80				9.63	17.57
Ave. C R	10.80		19.40		17.60		23.80		19.00		14.80					

ergograph pattern is an indication of further ergograph patterns and probably little else.

The results in general suggest the conclusion that individuals do produce the same kind of pattern of decrement in successive performances of a given task, but that this pattern is specific to the task and does not correspond to decrement patterns in other tasks.

2. *Correlations of Points on the Work Curves at Which Output Fell Below 50 Percent and 75 Percent of the Total Decrement Suffered*

Inspection of the work curves produced in each task revealed, in most cases, a general trend downward from the peak of production to the point of greatest decrement. Previous work with the ergograph (1) showed that individuals tended to reach approximately the same degree of decrement at about the same relative time in successive performances. It was desirable to apply the same type of analysis to the present data to see if there was any correspondence between the relative times at which an individual suffered a certain amount of decrement in different tasks. The following procedure was used: the work output for each task consisted of 20 work units (each ergogram was also reduced to 20 units by taking the median stroke height of each 20th of the work curve). The 20ths of each work curve at which the level of performance fell below 50 percent and 75 percent of the highest value were recorded separately. Correlation coefficients between these positions (in terms of 20th of the work curve) were then calculated: (1) each task was correlated with a subsequent performance of the same task for both degrees of decrement (50 percent and 75 percent); (2) each task was correlated with each of the other three in the same manner.

The average position of 50 percent and 75 percent decrement for each work session is shown in Table II. Also in Table II are shown the inter-task and intra-task correlations between these positions.

TABLE II

AVERAGE POSITIONS, ON A SCALE OF 20, AT WHICH PRODUCTION FELL BELOW 50 PERCENT AND 75 PERCENT IN EACH WORK SESSION AT FOUR TASKS AND CORRELATIONS BETWEEN THE VARIOUS WORK PERIODS

(Correlations between different tasks were calculated from the results of the second work period of each task)

	50%				75%			
	M	S.D.	r	P.E.	M	S.D.	r	P.E.
Writing I	5.65	2.84			8.80	3.76		
II	6.55	3.32	.126	.10	10.55	4.68	.080	.11
Counter I	9.40	3.46			12.60	4.00		
II	9.20	3.16	.405	.09	11.75	3.40	.404	.09
Drill I	4.73	3.26			5.70	3.98		
II	4.68	2.66	.662	.06	6.62	3.72	.631	.06
Ergog. I	14.87	3.45			18.18	2.32		
II	14.00	3.65	.740	.05	17.72	2.73	.742	.05

Correlations between second performances

	50%		75%	
Writing and Counter	.201	±.10	−.069	±.11
Writing and Drill	.130	±.11	.216	±.10
Writing and Ergogr.	−.052	±.11	−.054	±.11
Counter and Drill	−.140	±.11	.062	±.11
Counter and Ergogr.	−.228	±.10	.078	±.11
Drill and Ergograph	.214	±.11	.233	±.11

In some cases there were a number of sudden drops from which recovery would take place. In these cases an arbitrary criterion was set up by which a point was not considered unless there were no more than three such recoveries in the rest of the curve. In the Drill task, however, three cases had to be dropped because they showed no consistent downward trend but finished at about the same level as that at which they had started, although numerous falls occurred in the course of the work.

The results from correlation of the points of 50 percent and 75 percent decrement confirm, in general, the results of the technique of judging. Correlation of 2 successive performances of the same task resulted in reliable correlations for three of the tasks. The Writing task was not reliably correlated with itself. In the judging, the Writing task also showed the lowest frequency of correct match-

ing. No reliable correlations between the tasks were found; the correlation between Writing and Drill was highest; Writing and Drill also received the highest number of correct matchings in the judging (Table I-*B*). The same general conclusions can be drawn from this treatment of the data: subjects tend to work in the same way at the same task, regardless of the nature of the task, but the same subjects will work differently in different tasks.

3. *Correlation of Percent of Decrement*

Inspection of the work curves indicated that certain individuals tended to suffer approximately the same degree of decrement on repeating a task. It was decided to discover how general this tendency was and whether there was any relationship which would carry over into the different tasks. To this end the percentage of decrement each individual suffered in each work session at each task was calculated by dividing the difference between the highest and lowest scores by the highest score. The ergograph task was not considered in this treatment because subjects reached a point of zero output in this task. Table III presents the correlation ratios both for two performances of the same task and between the second performances of the several tasks.

TABLE III

AVERAGE DECREMENTS IN THREE TASKS IN PERCENT, AND CORRELATIONS BETWEEN THESE DECREMENTS

	Writing		Counter		Drill	
	I	II	I	II	I	II
Mean	36.88	29.12	143.75	126.88	28.75	28.37
S.D.	9.95	8.80	56.75	62.75	9.20	7.50
r	.481	±.08	.777	±.045	.274	±.09
	Writing and Counter		Writing and Drill		Counter and Drill	
r	.281	±.09	.113	±.11	.120	±.105

From Table III we find that there are reliable correlations in percent of decrement for the writing and counter tasks. The correlations seem to increase with the increase in percent of decrement and seem to be, therefore, functions of the task—those tasks in which a large decrement is suffered by most subjects will tend to correlate higher. There is no reliable relationship between percentages of decrement in the different tasks, however, and prediction cannot be made from one task to another.

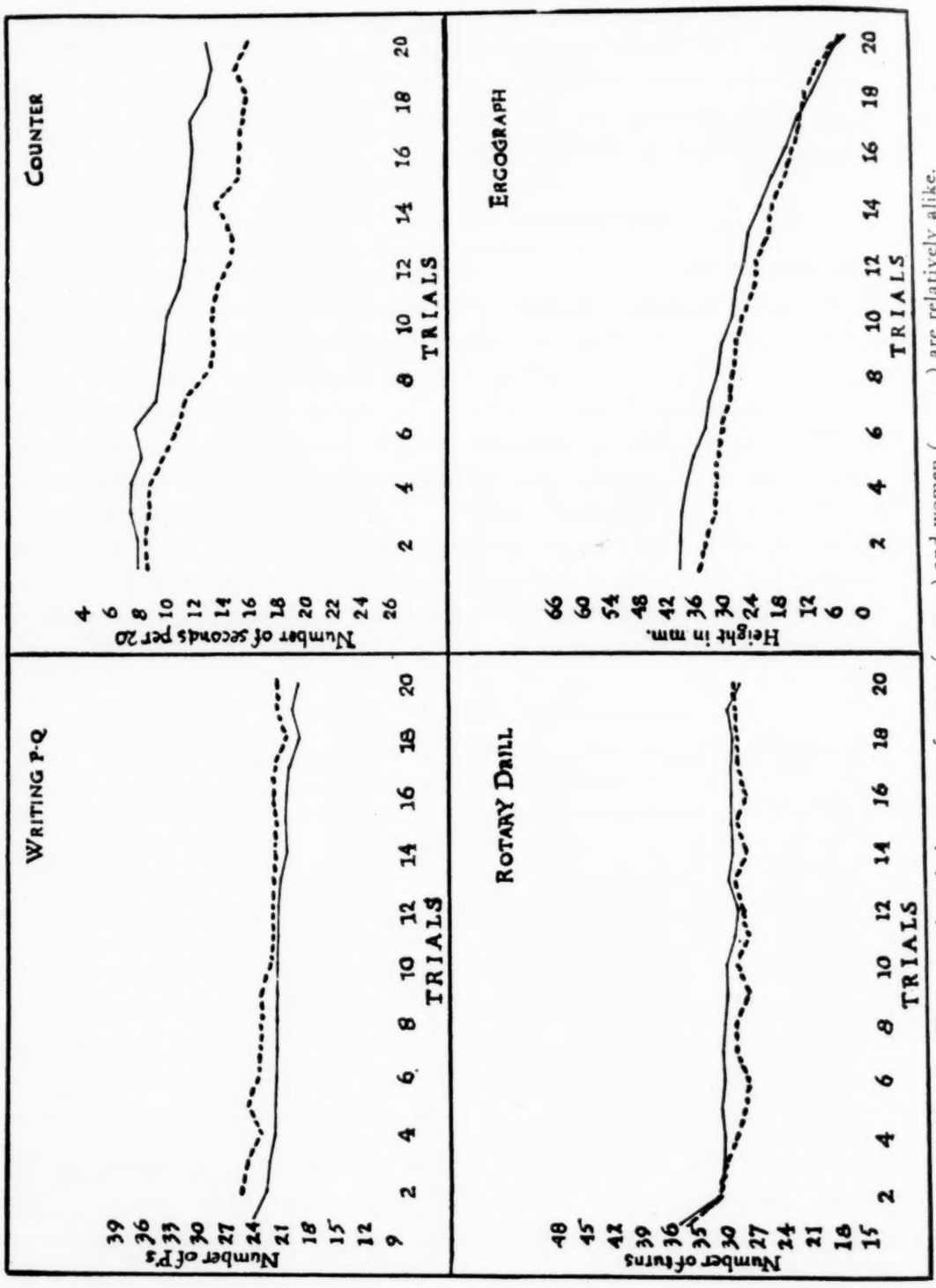


FIG. 4. Patterns of work decrement for men (——) and women (. . . . .) are relatively alike.

4. *Sex Differences*

Since both men and women served as subjects, it was decided to see if any general difference could be observed between the sexes. Inspection of the individual curves suggested a negative answer as women tended to produce as many varieties of curves as did the men. Group curves were plotted by averaging the 20 points in each curve made by men, and then by women. These group curves are shown in Fig. 4. Inspection of these curves reveals no interesting sex differences, and certainly no reliable ones. Women in general tend to drop in the level of production sooner, especially in Counter and Drill tasks. Except for the Writing task, men have a slightly higher general level of performance in the various tasks, which is not unexpected.

Discussion

The various methods of treatment applied to the data revealed two distinct trends: (1) the patterns of decrement in successive performances of the same task corresponded fairly well; (2) there was little or no resemblance among the various tasks. The results of the present investigation are similar to those found by investigators of various motor skills. Seashore (**14**) reported various motor tests (level of performance, not pattern of decrement) to have high reliability but low correlations with other motor performances and more complex motor skills such as typing, athletics, and musical ability. Gutstein (**3**) found no relationship among the ways an individual worked with various types of materials like clay, wire, paper, etc. Gutstein was not interested in decrement but merely in the methods of work, and since patterns of decrement will vary with the task it seems that there will be little if any transfer either of methods or decrement patterns from one task to another.

An inspection of the sample curves and of the curves in Fig. 4 suggests a possible answer to the lack of consistency among the tasks. Each task apparently favored one certain type of curve and individual variations fell mostly within this general pattern. The Writing task, for example, tended to produce a curve in which there was a relatively sharp drop from the original high level almost immediately; the rest of the curve was more or less level. The Counter task, on the other hand, produced a curve in which an original high level could be maintained for some time; then a break would occur, usually rather suddenly with variations in the manner of decrement toward the end of the curve; the Drill task resembles the Writing task at the beginning, although the original drop is steeper; but instead of reaching a level, there were numerous variations, erratic falls and

rises, in contrast to the relatively level Writing curves. The Ergograph curves, like the Counter curves, tended to prolong an original high level for some time before the subject began to drop. In short, different tasks predetermine the general nature of the curve of decrement; individual variations take place within the extremes set down by the nature of the task.

One other matter might be considered with reference to the Drill and Writing tasks and any other tasks which extend over a period of time. In such tasks a considerable loss of efficiency occurs in the very early part of the work (**15**, p. 622). It may be that closer analysis of the progress of decrement in these early stages of the work might show closer similarity to such short work periods as the ergograph involves. This closer analysis, however, would not enable one to draw conclusions about decrement patterns in long-time work.

An interesting finding was that the degree of consistency of decrement pattern in a given task decreases as the complexity of the task increases. Such tasks as simply bending one's finger in a pulling motion or bending two fingers in a pushing motion showed more consistency to themselves on repetition than did more complicated tasks like turning the crank of a drill or writing letters. This trend suggests that as the tasks increase in complexity and difficulty there will be less and less resemblance in decrement patterns although there may be similarity in other features of the work, such as methods of approach, spacings of rest, motivational differences at different periods of the work, etc. This relationship between simplicity of task and degree of consistency of decrement patterns also suggests that physiological factors are not perhaps the most important, but only that a physiological basis underlies the psychological causes of variations. An illustration from ergographic work will make this clearer. When a subject is raising a weight with his finger or arm the task is at first fairly simple; after a period of work pain sensations begin to be experienced. The period before pain sensations begin may be about the same length in successive work sessions. At this point psychological factors may enter; one person may strive to overcome the sensations in the hope of some 'second wind' relief; another may be willing to endure them because of pride, rivalry, etc.; still another subject may give in to the pain and cease working because he does not consider the task important enough. The physiological factors leading to the pain sensations cause the subject to make some adjustment at a fairly constant time period in the work. The nature of this adjustment will depend on psychological factors. Similarity between two performances of the same task will thus be a result of both factors.

In more complicated work the physiological factors will not occur in the same time order because different muscle groups may be substituted on different occasions of working at the same task and the relative times at which different muscle groups will begin to fatigue will differ so that the factor of physiological similarity will be absent in more complex tasks and performances will differ to that extent with reference to the patterns of decrement.

Summary and Conclusions

The hypothesis that patterns of decrement in the finger ergograph may indicate the general pattern of decrement that a given individual will undergo in other routine performances was investigated. Forty subjects worked twice at four different routine tasks: finger ergograph, writing letters, turning the crank of a hand drill, and pressing keys under tension alternately with the first and second fingers. Each task was continued long enough to provide twenty units of production. The units were then plotted on squared paper as curves of decrement. Analysis of the two work curves produced by each subject in each task revealed that:

1. Judges were able to match the two curves produced by each individual in the same task (in eight groups of five each) far in excess of chance. The highest number of correct judgments per task were in the following order: pressing keys, ergograph, writing letters, turning crank.
2. The judges were not able to match successfully the curves made by the same individuals in different tasks; chance scores prevailed.
3. The same general trend was found in correlation of the points on the curves at which the level of production fell below 50 percent and 75 percent, that is, the curves in the same task correlated reliably; those for different tasks were not reliable.
4. The same trend was found in correlating the percentage of decrement undergone in the tasks.
5. No significant sex differences were found between the 16 women and 24 men who served as subjects.

The findings reported above indicate that the pattern of decrement in the ergograph is not to any reliable extent correlated with patterns of decrement in other routine tasks, nor do other routine tasks show any reliable similarity with each other in pattern of decrement. The fact that each task, taken by itself, shows a reliable degree of similarity with repetition suggests that the pattern of decrement in any task is specific to the task itself and is no indicator

of decrements in other activities. This conclusion is supported by the finding that each of the tasks studied tended to result in a general pattern which set the limits for each task and excluded the patterns of other curves. The finding that the degree of similarity of repeated performances of the same task increased with the simplicity of the task suggests that physiological factors which are more uniform in simple muscular action are largely responsible for the basic similarities in the patterns of decrement and that more complex tasks will have less similar patterns of decrement. In general, the conclusion seems warranted that the pattern of decrement both in ergograph and in other tasks is a specific trait. This specificity corresponds with conclusions of investigators in the field of motor skills.

(Manuscript received September 27, 1940)

References

1. Bugelski, B. R., The consistency of individual differences in the pattern of work decrement, *J. exp. Psychol.*, 1941, **28**, 326–339.
2. Enke, W., Die Psychomotorik der Constitutionstypen, *Zsch. f. ang. Psychol.*, 1930, **36**, 1–56.
3. Gutstein, C., Zur Frage des Arbeitstypus, *Indus. Psychotechn.*, 1932, **9**, 210–218.
4. Koch, H., Untersuchungen uber den individuellen Arbeitsrhythmus an Landarbeitern, *Psychotechn. Z.*, 1933, **8**, 58–65.
5. Lehmann, H., Messung des Kraftimpulses, *Indus. Psychotechn.*, 1928, **5**, 265–272.
6. Manzer, C. W., An experimental investigation of rest pauses, *Arch. Psychol.*, 1927, **14**, No. 90, pp. 84.
7. Marks, E., Individual differences in work curves, *Arch. Psychol.*, 1935, **27**, No. 186, pp. 60.
8. Miles, W. R., A rotary motility test, *J. gen. Psychol.*, 1928, **1**, 374–377.
9. Misefari, E., *La personalita nel lavoro*, Milan, Contemporanea, 1932. (not seen)
10. Mosso, A., *Fatigue.* (Trans. by M. Drummond and W. B. Drummond. 1904, New York, Putnam, pp. xiv, 334.
11. Pressey, S. L., A machine for automatic teaching of drill material, *Sch. and Soc.*, 1927, **25**, 549–552.
12. Ricci, A., Lo sforzo ergorapfico e dinamagrafico specie dal punto di vista della reintegrations, *Morganni*, 1932, **11**, 348–349. (not seen)
13. Robinson, E. S., Work of the integrated organism, *Handbook Gen. Exper. Psychol.*, C. Murchison, ed., Worchester, Mass., Clark Univ. Press, 1934, 571–650.
14. Seashore, R. H., Individual differences in motor skills, *J. gen. Psychol.*, 1930, **3**, 38–66.
15. Yochelson, S., Individual differences in ergography, *Amer. J. Psychol.* (in press).
16. Yochelson, S., Effects of rest pauses on work decrement, Yale Univ., Ph.D. Dissertation, May 1, 1930, pp. 102.

THE RELATION BETWEEN THE CRITICAL DURATION AND INTENSITY IN BRIGHTNESS DISCRIMINATION *

BY MARGARET KELLER

Butler Hospital, Providence

A recent discussion of intensity discrimination in vision by Graham and Kemp (**2**) has called attention to the fact that a reciprocal relation exists between ΔI and its duration, τ, up to the limits of a 'critical duration,' τ_c. Beyond this critical duration the discrimination is independent of exposure time and depends only on ΔI.

Graham and Kemp's data indicate that the critical duration is a function of the basic adapting intensity, I. As I increases, the critical duration decreases. This fact raises a practical problem in the determination of intensity discrimination thresholds. Where the time of exposure for ΔI is constant and well below the critical duration for all levels of intensity, I, Hecht's theoretical relationship (**5**) between $\Delta I/I$ and I describes the experimental findings. However, if the duration of ΔI is greater than the critical duration, the data deviate from theory. This means that to obtain unequivocal results in intensity discrimination it is necessary either (*a*) to employ a duration of ΔI well below the critical duration or (*b*) to apply a correction for longer exposures. The data of Graham and Kemp were not adequate to determine a precise relation between the critical duration and intensity, and for this reason the authors were not able to develop an exact correction.

In the present paper the intensity discrimination function has been examined over a much smaller range of durations than was true in the experiment of Graham and Kemp. By this procedure, experimental determinations have been made at much smaller intervals of duration, and thus a more precise determination of critical duration values, τ_c, is possible. These relatively exact measures are treated as a function of the prevailing intensity, I, and with the demonstration of a well defined relationship between these variables, it is possible to estimate the influence of the critical duration on the form of the intensity discrimination function. This analysis is particularly revealing as it bears on the question of conditions necessary for the appearance of a final rise in the intensity discrimination curve.

* This study was carried out in the Psychology Laboratory of Brown University. Some of the work was done while the author held the Miss Abbott's School Alumnae Fellowship and the study was financed in part by the Carnegie Foundation. The author wishes to express appreciation for this assistance and also to thank Professor C. H. Graham for his guidance throughout the investigation.

Method

The apparatus used in the present investigation is similar to that used in the earlier study by Graham and Kemp (2). A small change in the optical system involves the substitution of frosted glass for the opal glass in the stimulus semicircles of the former experiment. Attending this change is a slight modification in the dimensions of the stimulus configuration observed by the subject. A final difference between the conditions of the two experiments lies in the fact that an artificial pupil (3 mm in diameter) has been provided in this experiment for the better control of stimulation.

Light from a 1000 watt lamp, after passing through a cooling cell, a lens, and a holder for Wratten neutral tint filters, is divided into two beams by a system of four prisms. The two beams pass through two pairs of convex lenses and impinge on semicircular apertures in a metal screen. This screen is fastened to the front wall of the subject's cubicle in such a way that the two stimulus objects are directly in front of the subject and at the level of his eyes. One of the beams contains a photographic wedge and a balancing wedge; manipulation of the former allows for an equation of the intensities on the two semicircles. The semicircles are covered with three thicknesses of frosted glass on the side toward the light source (as contrasted with the opal glass of the earlier experiment) and they are separated by a metal fin which projects perpendicularly from the screen. At a distance of 60 cm. each semicircle has a radius of 44 minutes, and the separation between semicircles subtends a visual angle of about 6 minutes. Thus the total stimulus object subtends a visual angle of about 1.5 degrees and falls for the most part within the limits of the fovea. The 3 mm artificial pupil nearly eliminates variations due to changes in pupil size.

An additional light beam is employed for the presentation of ΔI in the form of a flash. The details of the ΔI beam are similar to those described by Graham and Kemp (2). Holders for neutral tint filters and a wedge with balancing wedge are present in the beam; exposure devices as previously described are placed at the focal point. For long durations (0.08 sec to 0.2 sec), the control of exposure is effected by means of a synchronous motor driven exposure device; durations of 0.05 second and shorter are obtained by means of an apparatus which consists essentially of a large disk attached to the axle of a phonograph motor. In order to obtain single flashes with the latter device a hand operated, flash-selecting shutter is placed in the third beam between the frosted glass and the large disk on the phonograph motor.

The procedure for any given experimental session consisted in varying the photographic wedge in the second beam until an equation point was determined. This was always done at the highest intensity of the two patches with the ΔI beam occluded. After the determination of the equation point measurements were made of the increment, ΔI. The wedge in the third beam was set in such a position that a flash of light, clearly visible to the subject, was added to the intensity on the left semicircle. The experimenter then determined the threshold by decreasing the intensity of this beam. After this, the wedge was placed so that the added flash was not visible to the subject, and the intensity was gradually increased until a report of the flash was obtained. An average of these two measurements was taken as the threshold increment, ΔI. Four such determinations were made at each level of prevailing intensity for each of the two subjects, flashes of ΔI being presented at approximately 10 second intervals. After the threshold for the given duration of flash had been determined for a given prevailing intensity, I, the filters in the third and divided beams were changed and determinations for ΔI were made at another intensity. This procedure was followed during any experimental session with a constant duration at eleven prevailing intensities. Determinations progressed from the lowest intensity level to the highest in half of the series; in the other half, determinations were begun at the highest intensity. Five minutes of dark adaptation were allowed in the former case. The results for both series show a high degree of agreement, a finding which probably indicates that adaptation was adequately controlled. Observations were monocular in all determinations. The durations of ΔI which were used were: 0.013, 0.02, 0.03, 0.05, 0.08, 0.13, and 0.2 second.

Discussion of Results

The results of the experiment are given in Table I and Fig. 1. In accordance with conventional procedure, Fig. 1 presents the logarithm of the energy of the flash ($\log \Delta I \cdot \tau$) as a function of the

TABLE I

RELATION BETWEEN THE INTENSITY AND DURATION OF THE INCREMENT (ΔI) AT VARIOUS LEVELS OF INTENSITY

Log I (photons)	Subject	Log $\Delta I \cdot \tau$						
		0.013 sec.	0.02 sec.	0.03 sec.	0.05 sec.	0.08 sec.	0.13 sec.	0.2 sec.
4.32	Br.	——	1.78	1.95	1.95	2.08	2.39	2.56
	Bl.	1.61	1.69	1.85	2.03	2.31	2.56	2.80
3.72	Br.	1.17	1.20	1.33	1.45	1.63	1.81	2.10
	Bl.	0.99	1.12	1.27	1.43	1.74	2.06	2.33
3.32	Br.	0.73	0.90	0.87	1.03	1.17	1.43	1.59
	Bl.	0.63	0.75	0.84	1.08	1.34	1.61	1.88
2.72	Br.	0.11	0.34	0.35	0.39	0.51	0.71	0.92
	Bl.	0.01	0.21	0.25	0.46	0.64	1.00	1.28
2.32	Br.	−0.24	−0.06	−0.06	−0.02	0.17	0.40	0.57
	Bl.	−0.37	−0.16	−0.19	0.04	0.25	0.48	0.78
1.72	Br.	−0.62	−0.47	−0.49	−0.44	−0.42	−0.14	0.02
	Bl.	−0.77	−0.55	−0.60	−0.39	−0.22	−0.12	0.28
1.32	Br.	−0.89	−0.83	−0.79	−0.73	−0.76	−0.52	−0.27
	Bl.	−1.04	−0.81	−0.91	−0.70	−0.54	−0.39	−0.10
0.72	Br.	−1.17	−1.16	−1.08	−1.01	−1.06	−0.91	−0.67
	Bl.	−1.28	−1.19	−1.05	−1.01	−0.99	−0.76	−0.44
0.32	Br.	−1.40	−1.30	−1.24	−1.15	−1.20	−1.04	−0.86
	Bl.	−1.34	−1.32	−1.22	−1.20	−1.06	−1.05	−0.68
−0.28	Br.	−1.57	−1.45	−1.48	−1.38	−1.42	−1.18	−1.06
	Bl.	−1.64	−1.39	−1.33	−1.46	−1.31	−1.28	−1.02
−0.68	Br.	−1.76	−1.51	−1.54	−1.61	−1.56	−1.46	−1.31
	Bl.	−1.88	−1.57	−1.57	−1.70	−1.61	−1.53	−1.28

logarithm of the duration (τ). The curves are for seven exposure durations at each value of I; each point represents an average of four measurements. This method of presentation is often employed [Hartline (**4**), Karn (**7**), Graham and Margaria (**3**), Graham and Kemp (**2**)] and it is convenient because, with logarithmic plotting, a line having a slope of zero represents the relation $\Delta I \cdot \tau = C$, while a slope of unity indicates that ΔI = *Constant*. The number to the

left of each curve in Fig. 1 indicates the logarithm of the prevailing intensity I at which the product of ΔI and τ was calculated.

The results of Fig. 1 are in agreement with those reported by

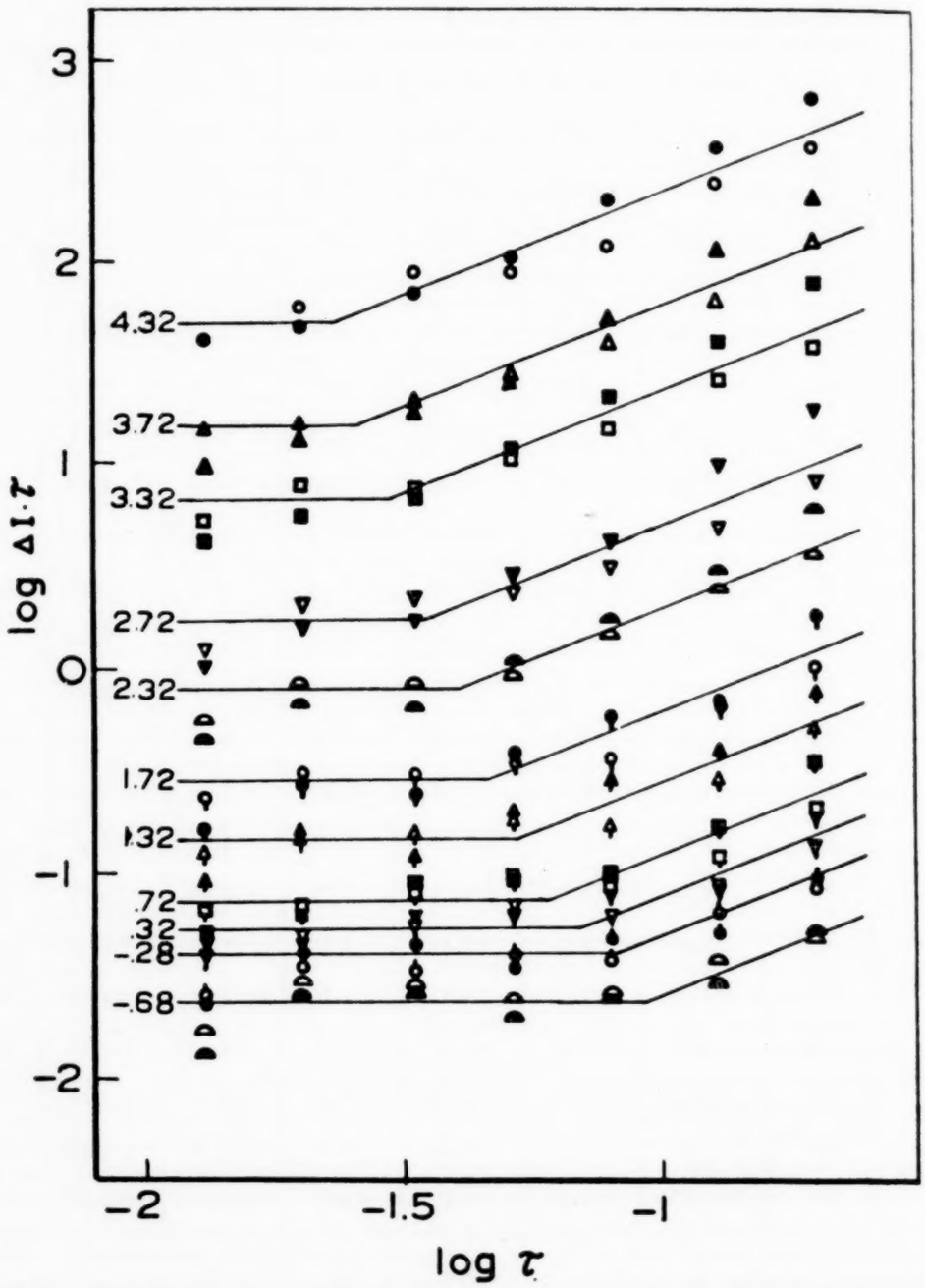


FIG. 1. The relation between ΔI and I for various values of I. The horizontal lines represent the equation $\Delta I \cdot \tau = constant$; the inclined lines, $\Delta I = Constant$. The number beside each curve represents the logarithmic value of the basic intensity. Filled symbols, subject *Bl*; open symbols, subject *Br*.

Graham and Kemp (**2**). The figure demonstrates that the product of ΔI and τ is constant throughout the lower range of durations for all levels of intensity used. At longer durations, however, the

reciprocity relation (horizontal line) no longer holds. The new relation which accounts for effects observed at longer durations is shown in Fig. 1 by a curve drawn with a slope of unity. This inclined line represents the expression $\Delta I = Constant$. It may be observed that *Bl*'s data deviate slightly from this latter relation. Probably a line of somewhat greater slope than unity would fit the experimental points better. However, the deviation is not serious. *Br*'s data are fitted by the equation, and as an expression it accounts well for the general relation exhibited by both subjects.

The duration corresponding to the intersection of the horizontal and inclined curves of Fig. 1 is the 'critical duration.' For durations longer than this critical duration the Bunsen-Roscoe law does not apply, and the new expression, $\Delta I = Constant$, comes into play. It is obvious that the value of the critical duration, as determined by observing the point of intersection of the two curves, may vary within the limits of goodness of fit of the horizontal and inclined lines. The values which were chosen on the basis of final fit are entered in Table II. This table records the manner in which the critical

TABLE II

CRITICAL DURATION AS A FUNCTION OF INTENSITY

Log I	Log Critical Duration	Log I	Log Critical Duration
4.32	−1.64	1.32	−1.28
3.72	−1.59	0.72	−1.22
3.32	−1.53	0.32	−1.16
2.72	−1.46	−0.28	−1.10
2.32	−1.39	−0.68	−1.04
1.72	−1.34		

duration varies as a function of the prevailing intensity I. As was true in the case of the observations by Graham and Kemp, the critical duration shows a systematic and regular variation with the level of I: the higher the value of I, the smaller the value of the critical duration. The relationship between these variables is shown in Fig. 2, where the values of the critical durations, read from Fig. 1, are plotted as a function of the prevailing intensity I.

It should be stated that the critical durations as plotted in Fig. 2 were obtained on the basis of two criteria: (*a*) the extent to which they might serve as legitimate 'anchoring points' for the horizontal and inclined lines of Fig. 1; and (*b*) the regularity of the function to which they would lead.[1] Inasmuch as the equation

[1] The point of intersection or the critical duration for each intensity level was also determined by a somewhat less arbitrary method. Parallel lines enclosing the points with greatest deviations were drawn for each of the two curves at each level of intensity. The distance between the two extreme intersections was measured off on the abscissa and the mid-point selected as the most probable value. The values obtained in this manner varied only slightly from those recorded above. The equation for the relation between the critical duration and intensity was in this case:

$$\tau_c = 0.067\, I^{-0.11}.$$

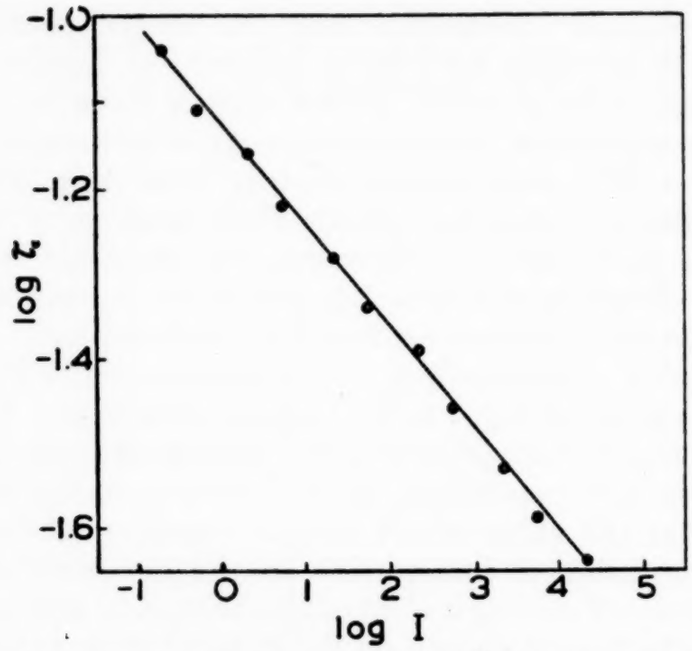


FIG. 2. The relation between the critical duration (τ_c) and the basic intensity, I. The method used in deriving the curve is discussed in the text.

describing Fig. 2 is wholly empirical, there is justification for using the simplest possible function which (*a*) adequately predicts the results and later theoretical treatment and (*b*) still remains well within the limits of experimental error and normal scatter of the data. The curve of Fig. 2 meets these requirements. The points are described by the equation

$$\tau_c = \tau_0 I^{-0.12}, \tag{1}$$

where τ_c is the critical duration and τ_0 is the critical duration for an intensity value of unity. For these data, τ_0 has a value of 0.074. This equation conveniently formulates the mode of variation of critical duration and prevailing intensity and serves as a precise representation of a factor which must be considered in the theoretical treatment of brightness discrimination.

Graham and Kemp (**2**), in their discussion of Hecht's (**5**) theory of intensity discrimination, have shown that it is the initial *amount* of photochemical decomposition on the introduction of ΔI which leads to the discrimination of $(I + \Delta I)$ from I. According to their argument

$$\frac{\Delta I}{I} \cdot \tau = \frac{c}{a^2 k_2}\left(1 + \frac{1}{(KI)^{1/2}}\right)^2 \tag{2}$$

for durations of ΔI lying below the critical duration at any level of I. For durations of ΔI equal to or exceeding the critical duration

$$\frac{\Delta I}{I} \cdot \tau_c = \frac{c}{a^2 k_2}\left(1 + \frac{1}{(KI)^{1/2}}\right)^2. \tag{3}$$

The importance of the present results derives from the fact that our findings provide a basis for conveniently modifying the expression of equation (3) in such a way as to indicate a partial solution of the perplexing problem: why do some intensity discrimination functions show a final upturn [*e.g.*, those of Koenig and Brodhun (**8**)] while others do not [*e.g.*, Hecht, Peskin and Patt (**6**)].

Let us consider equation (**3**). According to equation (1) $\tau_c = \tau_0 I^{-0.12}$. If $\tau_0 I^{-0.12}$ be substituted for τ_c in equation (3) we find that

$$\frac{\Delta I}{I^{1.12}} \cdot \tau_0 = \frac{c}{a^2 k_2}\left(1 + \frac{1}{(KI)^{1/2}}\right)^2. \qquad (4)$$

This expression is superior for practical purposes to equation (3) in that τ_0, unlike τ_c, is a constant, independent of I.

It is to be observed that the right hand expressions of equations (2) and (4) are identical for the same values of I. This means that, if we plot (*a*) $\log (\Delta I/I)/\tau$ against $\log I$ for values of τ less than τ_c and (*b*) $\log (\Delta I/I^{1.12})/\tau_0$ against $\log I$ for values of τ equal to or exceeding τ_c, we should derive a family of superimposed curves. This superposition of curves represents the fact that, whatever may be the values of τ, τ_0, or ΔI going to make up the value of the ordinate variable, this variable is always the same function of I.

The outcome of this test of theory is presented in Fig. 3. In constructing this graph the average $\Delta I/I$ values for both subjects have been multiplied by τ for durations which are less than the critical durations, as determined by substitution in equation (1). For durations of τ equalling or exceeding τ_c, $\Delta I/I^{1.12}$ values have been multiplied by τ_0, which in this experiment is equal to 0.074. Figure 3 shows that our theoretical development is supported by the data. The results in Fig. 3, with the possible exception of the data for the duration $\tau = 0.013$ sec, lie on a single curve. The discrepancy for the 0.013 sec data is uncertain in origin; in the light of earlier work of the same type where this deviation did not occur [Graham and Kemp (**2**)] it is probably unimportant.[2] The curve drawn through the data is the curve predicted from Hecht's theory, and it may be seen that the data are fitted by it in a satisfactory manner. Our intensity discrimination results, then, are adequately predicted by Hecht's hypothesis when allowance is made for the influence of the critical duration.

The data of this experiment are in a form which allows for a consideration of factors which might cause the final rise in the

[2] It seems unlikely that this discrepancy could be due to lack of 'suddenness of onset' since the total image of the ΔI beam was not more than 2 mm in width and the width of the slit for the 0.013 sec duration was 3.1 cm. It is possible that a practice effect entered as a disturbing factor. Although both subjects received preliminary practice, the 0.013 sec duration was the first series for each.

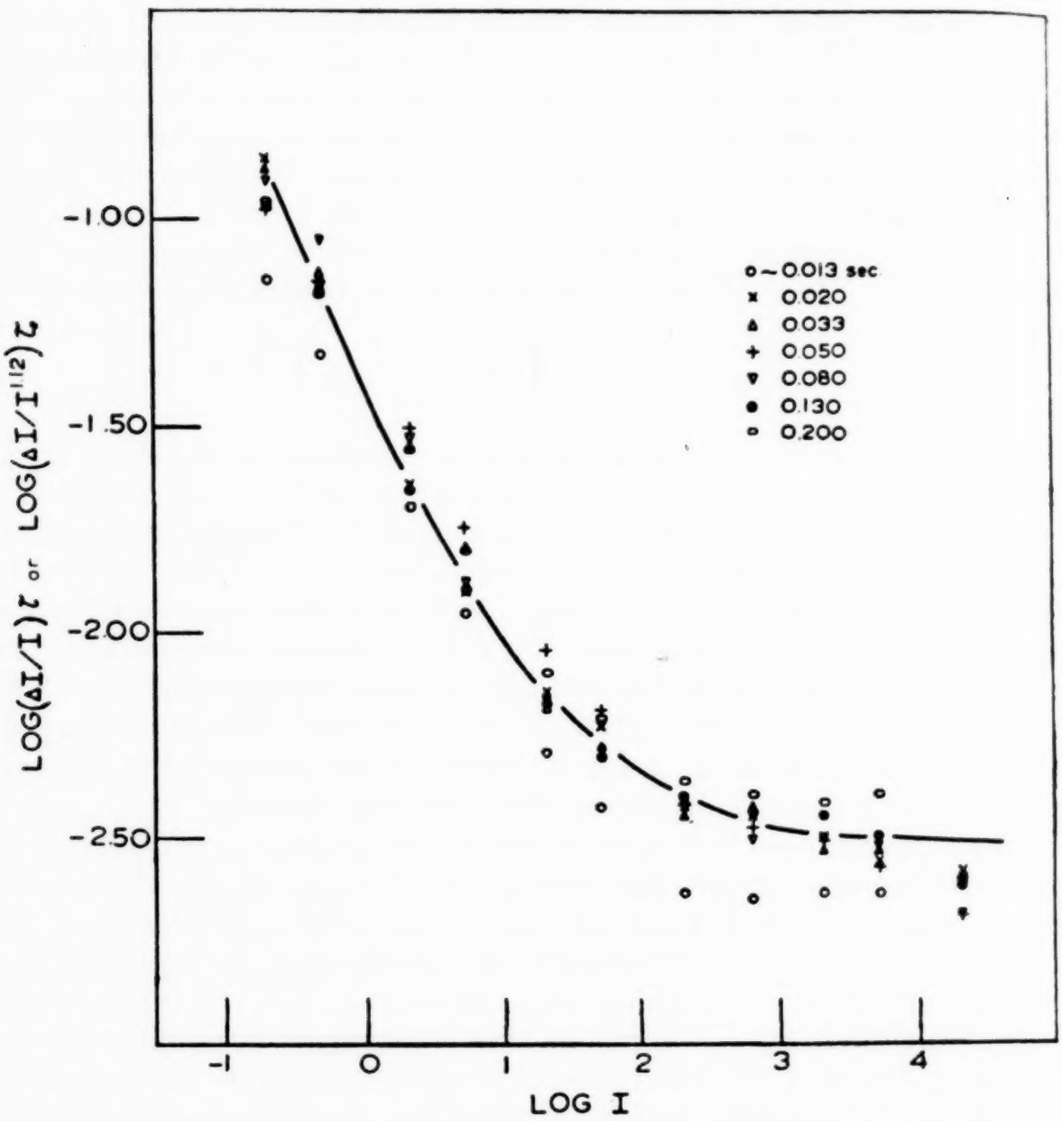


FIG. 3. $(\Delta I/I)/\tau$ as a function of I in terms of Hecht's theory. The curve drawn through the data is theoretical. For durations greater than τ_c the ordinate is to be read as $\log (\Delta I/I^{1.12})/\tau_0$.

discrimination function. It has already been emphasized that this is a problem of great importance in the test of theory. According to Hecht's (**5**) theoretical treatment, $\log \Delta I/I$ reaches a final steady minimum at high intensities and shows no final increase in value. Koenig and Brodhun's (**8**) data and all other data in which a secondary rise in the curve is reported are not fitted by Hecht's theoretical curve.

Steinhardt (**10**) made a detailed study of the relation between $\Delta I/I$ and I in the human eye and the dependence of this relationship on area of the test field and presence or absence of illuminated surround. The curves which he presents usually show no final

upturn but resemble those of Koenig and Brodhun in other respects. The data obtained without a surround are found to scatter widely, especially at high intensities. Steinhardt suggests that the appearance of the rise in the curve at high intensities depends on the illumination surrounding the test field and on the adaptation of the eye. Craik (1) offers evidence in support of this view.

Let us examine equations (2) and (4), which express the relation between $\Delta I/I$ and I for durations below and above the critical duration respectively. Equation (2) is similar to Hecht's final expression for the intensity discrimination function except that it involves τ. It may be assumed that for constant durations below the critical duration τ is contained within the constant c/a^2k_2 of Hecht's equation. Hence if we plot $\log \Delta I/I$ against $\log I$ for these short durations of exposure, below the critical duration, we should find that the resulting curve is the one theoretically derived by Hecht (5).

Equation (4) represents the theoretical function for events which occur with durations longer than the critical. In this equation it may be seen that the right hand expression does not predict $\Delta I/I$ values. It gives instead a variable which is proportional, through the constant τ_0, to $\Delta I/I^{1.12}$. This latter term is the proper variable for use with durations of τ greater than τ_c, because it corrects for the influence of the critical duration which is a function of I.

The curves of Fig. 4 indicate what may occur in experiments on intensity discrimination when exposure times are long and when the influence of the critical duration goes unrecognized. The curve marked A, plotted in arbitrary units, is the curve resulting when $\log \Delta I/I^{1.12}$ is plotted against $\log I$. This curve has the form which would be expected on the basis of Hecht's theory and it shows no final upturn. Curve B, on the other hand, results from a plot of $\log \Delta I/I$ against $\log I$ for high values of τ (*i.e.*, $\tau > \tau_c$). The influence of the lack of correction for critical duration, as in equation (4), is shown by the fact that the curve passes through a minimum and has a final upward bend.[3]

The adequacy of this interpretation may be verified by the data of the present experiment. For durations of ΔI below the critical duration the curve should reach a final steady minimum, whereas for those durations beyond the critical the curve should rise at high intensities. The curves of the present experiment are in accord with this expectation. For the shortest durations (0.013 and 0.02 sec) there is no trace of a final rise. However, the rise does occur in the curves for the longest durations. Figure 5 gives the plot of $\log \Delta I/I$

[3] Both curves were computed with a value of unity for the constants τ_0, K, and c/a^2k_2. Curve B was calculated by multiplying the right hand side of equation (4) by $I^{0.12}$, thus giving an expression for $\Delta I/I$ rather than for $\Delta I/I^{1.12}$.

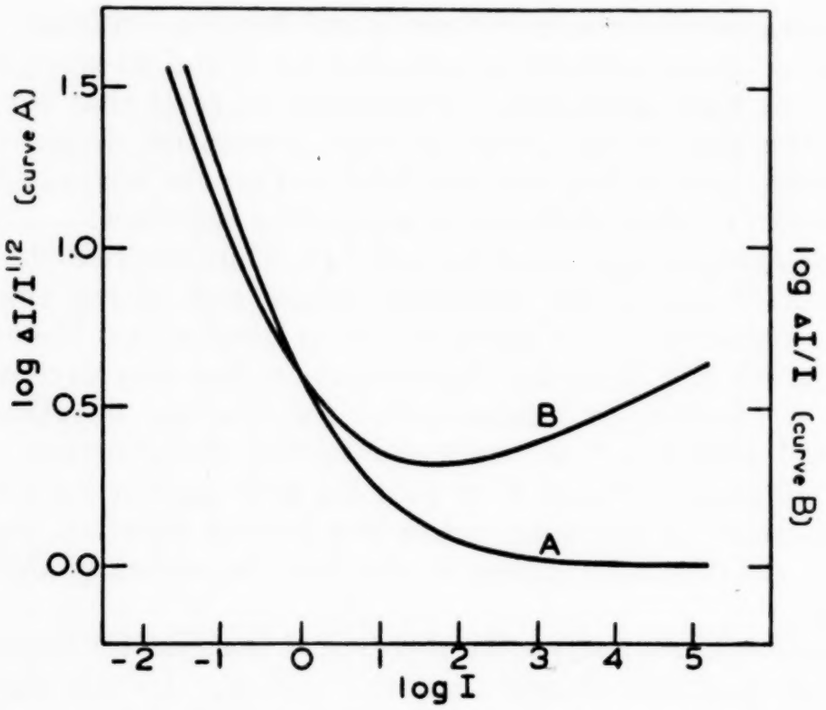


FIG. 4. Two types of intensity discrimination function obtained for durations of ΔI greater than the critical duration. In Curve *A*, $\log \Delta I/I^{1.12}$ is plotted against $\log I$ according to equation (4). Curve *B* represents the variations of $\log \Delta I/I$ with $\log I$ for the same conditions. All values are in arbitrary units.

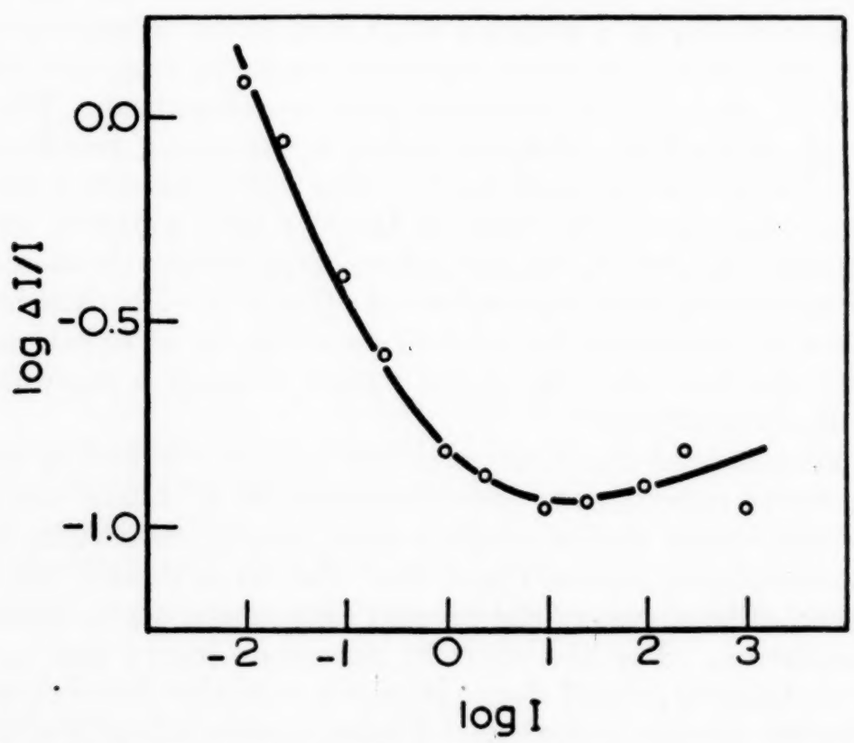


FIG. 5. Log $\Delta I/I$ plotted against $\log I$ for the 0.2 sec duration of ΔI. The curve drawn through the data is constructed theoretically in a manner similar to Curve *B* of Fig. 4.

vs. $\log I$ for the longest duration employed (0.2 sec). It will be observed that the final rise in this curve is well marked and unequivocal. The line drawn through the data is the theoretical curve for a variable critical duration (as in curve *B*, Fig. 4). Except for an irregularity at the highest intensity, the curve adequately describes the data and gives us experimental justification for the conclusion that the relationship between $\Delta I/I$ and $\log I$ normally shows a final upturn.[4]

This finding may, in part, resolve the discrepancy between experiments on the question of a final upturn in the curve. For long continued exposures, as in the work of Koenig and Brodhun (**8**), a plot of $\log \Delta I/I$ against $\log I$ would be expected to give a curve with a final rise, whereas the results of Hecht, Peskin and Patt (**6**), obtained with short durations of ΔI (0.04 sec), should not show this effect.

It is probable that variation in τ_c is not the only factor which is important in determining the presence or absence of an upturn; certainly it cannot explain the results of Steinhardt (**10**) or Smith (**9**) who found no rise with long continued observation. Possibly, as Steinhardt indicates, the condition of adaptation is an additional important determinant of the shape of the curve. However, our analysis does show that complications arising from the critical duration constitute an influence which must not be overlooked in the consideration of the shape of the intensity discrimination function. It seems likely that we have here at least a partial explanation of why some investigators report a final upturn in the curve and others do not. If the duration of the added increment (ΔI) is constant at a value below the critical duration for all levels of intensity employed, then we should expect the curve to reach a final steady minimum. If, on the other hand, the duration of ΔI is above the critical duration, a rise in the curve at high intensities is almost certain to appear.

Summary

1. A method is described for examining the influence on foveal intensity discrimination of variations in the duration (τ) of ΔI, the increment added to the basic intensity I.

2. In foveal intensity discrimination the Bunsen-Roscoe law ($\Delta I \cdot \tau = constant$) holds for exposures of ΔI up to the limit of a critical duration (τ_c) at all levels of the basic intensity, I. Beyond

[4] The only point which deviates seriously from theory is the one at the highest intensity. In all of our experiments with durations greater than the critical the final point is consistently low. At comparable intensities, some of Steinhardt's (10) curves seem to show the same effect, particularly in those instances where a surround is lacking.

the critical duration, intensity discrimination is independent of duration and $\Delta I = Constant$.

3. The critical duration decreases as the basic intensity increases according to an empirical relation of the form $\tau_c = kI^{-p}$, where k and p are constants.

4. A further analysis shows that, with durations of ΔI greater than τ_c, failure to consider the influence of the critical duration may alter the form of the intensity discrimination function in such a way as to produce a rise at high intensities. This observation may partially resolve some disagreements in the work of earlier investigators.

(Manuscript received October 18, 1940)

References

1. Craik, K. J. W., The effect of adaptation on differential brightness discrimination, *J. Physiol.*, 1938, **92**, 406–421.
2. Graham, C. H., and Kemp, E. H., Brightness discrimination as a function of the duration of the increment in intensity, *J. Gen. Physiol.*, 1938, **21**, 635–650.
3. Graham, C. H., and Margaria, R., Area and the intensity-time relation in the peripheral retina, *Am. J. Physiol.*, 1935, **113**, 299–305.
4. Hartline, H. K., Intensity and duration in the excitation of single photoreceptor units, *J. cell. comp. Physiol.*, 1934, **5**, 229–247.
5. Hecht, S., A theory of visual intensity discrimination, *J. Gen. Physiol.*, 1935, **18**, 767–789.
6. ——, Peskin, J. C., and Patt, M., The relation between $\Delta I/I$ and intensity for different parts of the spectrum, *J. Gen. Physiol.*, 1938, **22**, 7–19.
7. Karn, H. W., Area and the intensity-time relationship in the fovea, *J. Gen. Psychol.*, 1936, **14**, 360–369.
8. Koenig, A., and Brodhun, E., Experimentelle Untersuchungen über die psychophysische Fundamentalformel in Bezug auf den Gesichtssinn, *Sitzber. k. Akad. Wiss., Ber.*, 1889, **2**, 641–644.
9. Smith, J. R., Spatial and binocular effects in human intensity discrimination, *J. Gen. Psychol.*, 1936, **14**, 318–345.
10. Steinhardt, J., Intensity discrimination in the human eye. I. The relation of $\Delta I/I$ to intensity, *J. Gen. Physiol.*, 1936, **20**, 185–209.

SPECTRAL SATURATION CURVES FOR CHIMPANZEE AND MAN

BY WALTER F. GRETHER

Yale Laboratories of Primate Biology

For human beings with normal color vision the least saturated part of the spectrum is in the central region where yellow shades off into green, roughly at a wave-length of 570 mμ. Passing in either direction from this part of the spectrum the saturation increases, being maximal at the limits of visible radiation. These relationships between saturation and wave-length have been shown for normal human color vision by Priest and Brickwedde (**10**, **11**), Jones and Lowry (**7**), Purdy (**12**), Martin, Warburton, and Morgan (**8**), Nelson (**9**), and Wright and Pitt (**14**). In the common types of dichromacy or red-green color blindness, on the other hand, there is a neutral point, or point of zero saturation, in the blue-green region of the spectrum at about 500 mμ. In either direction from this neutral point in the spectrum of dichromats the saturation progressively increases, a fact demonstrated by Hecht and Shlaer (**6**). The spectral saturation relationships, therefore, provide a sharp differentiation between two-color and three-color visual systems, a differentiation in accord with the principles of the Young-Helmholtz color vision theory (see discussion). For this reason the measurement of spectral saturation as a function of wave-length should be of considerable value in the analysis of basic color vision mechanisms in animals.

A convenient measure of the saturation of spectral colors is what Priest and Brickwedde (**11**) have termed 'minimum perceptible colorimetric purity.' This is the lowest purity of spectral color diluted with white that still gives a perceptible hue sensation. Obviously, the lower a color is in subjective saturation the more of it must be added to white to be perceptible as hue. This type of measurement was used in the present study for comparing the spectral saturation curves for chimpanzee and man.

Apparatus, Method, and Subjects

The apparatus, except for the additions noted below, was the same as that described in an earlier paper (Grether, **2**). Spectral light of adjustable brightness and wave-length was supplied by a pair of monochromators. The light from either instrument could be projected upon either of two stimulus surfaces, which the subjects viewed through windows that could be pushed back to uncover food rewards. In this study, however, only one of the two monochromators was needed.

In addition to the spectral instruments there was an auxiliary apparatus for projecting white

light upon each of the two stimulus surfaces. This projector was mounted below the platform supporting the monochromators. Light was supplied by a 60-watt frosted, incandescent lamp encased behind an opal-flashed glass diffusing screen. By means of two lenses and mirrors (placed beside one another) two images of this diffused source-light were obtained, one upon each stimulus surface. Mounted with each lens was a calibrated parallelogram type slit for brightness adjustment. The mirrors deflecting the light downwards could be tilted so that the light through either lens could be cast upon either stimulus surface. In order to provide a white light resembling sunlight, a Macbeth 'Whiterlite' glass filter was mounted with the opal-flashed glass diffusing screen. The color temperature of this lamp and filter combination was 4029° K.[1] Though this lamp and filter combination did not provide an exact equivalent of sunlight (about 5400° K.), it was the most satisfactory arrangement the author was able to find after several other unsuccessful attempts to obtain suitable filters.

To obtain the very low intensities of spectral color needed in this experiment the brightness adjustment of the monochromator (variation in width of the exit slit) was supplemented by a pair of Polaroid discs, similar to those described earlier (Grether, 1). The discs were mounted in a tubular housing that could be placed behind the exit slit of the monochromator. A pointer attached to one of the discs followed a scale graduated in per cent of transmission.

In the testing of the animal and human subjects both stimulus patches were illuminated by white light (.11 millilamberts) from the auxiliary projector described above. To one of these was then added spectral light of a specified brightness and wave-length. At the same time the white light on this side was reduced by an equal amount to keep the two patches at the same brightness, and thus prevent the subjects' use of brightness as a secondary cue. In doing this it was necessary to assume that the spectral lights had the same brightness for the chimpanzee as for the human eye, an assumption at least partially justified by the author's recent experiments (2). The discrimination problem confronting the subjects, then, was the choice between a pure white and a white slightly tinted by spectral color.

The general method of measuring thresholds, for the ratio of spectral color to white, was the same as that described earlier in a study of hue discrimination (Grether, 2). During each 25-trial session five ratios were presented (five successive trials at each ratio), in the order of increasing difficulty. An attempt was made to choose ratios ranging from one that was very easily discriminated to one resulting in approximately chance success. Testing was continued until no further improvement appeared in five successive sessions. From these last 25 trials at each test ratio the 75 percent threshold was then derived by linear interpolation. In this manner thresholds were measured at each of 17 spectral points.

Two male chimpanzees were used in this investigation, both of which had been used in four preceding studies of color vision, and consequently were very proficient in discriminations involving color differences. These animals, Tom and Hal, were laboratory born, and about six and a half and four years of age, respectively, at the time of experimentation.

For purposes of comparison similar measurements were made on five human subjects. On only two of these were thresholds determined throughout the spectrum. The other three were tested only at the most crucial wave-lengths in the central spectral region. The human subjects were one woman (M. G.) and four men.

Results

In the experiments preceding the present one the chimpanzee subjects had been trained to choose the more red of two stimuli. In the present study, in order to use this already trained habit, testing was begun at the long wave-length end of the spectrum (680 mμ), with white plus red as the positive color. Thresholds were then measured at intervals, passing toward the shorter wave-lengths. The animals transferred readily from one wave-length to another

[1] This determination was made by Doctor W. E. Forsythe of the General Electric Company, whose coöperation was obtained through Doctor Lawrence H. Ott, instructor in biophysics in the Yale School of Medicine.

until 570 mμ (greenish-yellow) was reached. Here both animals made almost as many errors as correct choices, although, for the experimenter at least, there was a considerable color difference between the stimuli. Eventually the animals mastered this discrimination, and a threshold was successfully determined. When, however, the wave-length of the spectral color added to the white was reduced to 565 mμ both animals completely reversed their habit and consistently chose the white instead of the white plus spectral color. It was evident that the color relationship between the positive and negative stimuli had somehow become reversed. In order to continue testing, the color was shifted to the short wave-length end of the spectrum (460 mμ), where the animals also chose the white spontaneously. With the pure white now the positive stimulus, threshold measurements were continued at points increasing in wave-length up to 565 mμ. When again tested at 570 mμ the animals reverted to the original habit, and on most trials responded to the white plus color as the positive cue. It is obvious, because of the spontaneous habit reversal, that 570 mμ (or between 570 and 565 mμ) marked a crucial point in the spectrum of the chimpanzee subjects.

This phenomenon of reversal of the color relationship between the spectral hues and white occurred also for the human subjects, but at a slightly longer wave-length. The experimental instructions were to identify the more red of the two stimuli. Down to and including 575 mμ, all but subject A. S. identified the white plus color as the more red. Beginning at 575 mμ for subject A. S., and at 570 mμ for the other human subjects, the white plus color was described as distinctly greenish, and the white as reddish, apparently a result of contrast. For all five human subjects, therefore, the color reversal occurred above 570 mμ. For the chimpanzees, on the other hand, this reversal occurred between 565 and 570 mμ, apparently nearer the latter than the former.

In Fig. 1 are given the results in graphic form of the threshold measurements for all subjects. The solid symbols (squares and triangles) represent the threshold ratios of spectral color added to white for chimpanzees. The open symbols indicate the corresponding ratios for the human subjects, M. G. and V. N. Drawn free-hand through these is a broken line for chimpanzees and a solid line for human beings. In the insert at the bottom of the graph are peaks only of the curves for three other human subjects.

Since the saturation of a color is inversely proportional to the amount of it that must be added to white to be perceptible, the curves of Fig. 1 give the inverse picture of saturation relationships in the spectrum. The distinct peaks in the central region indicate

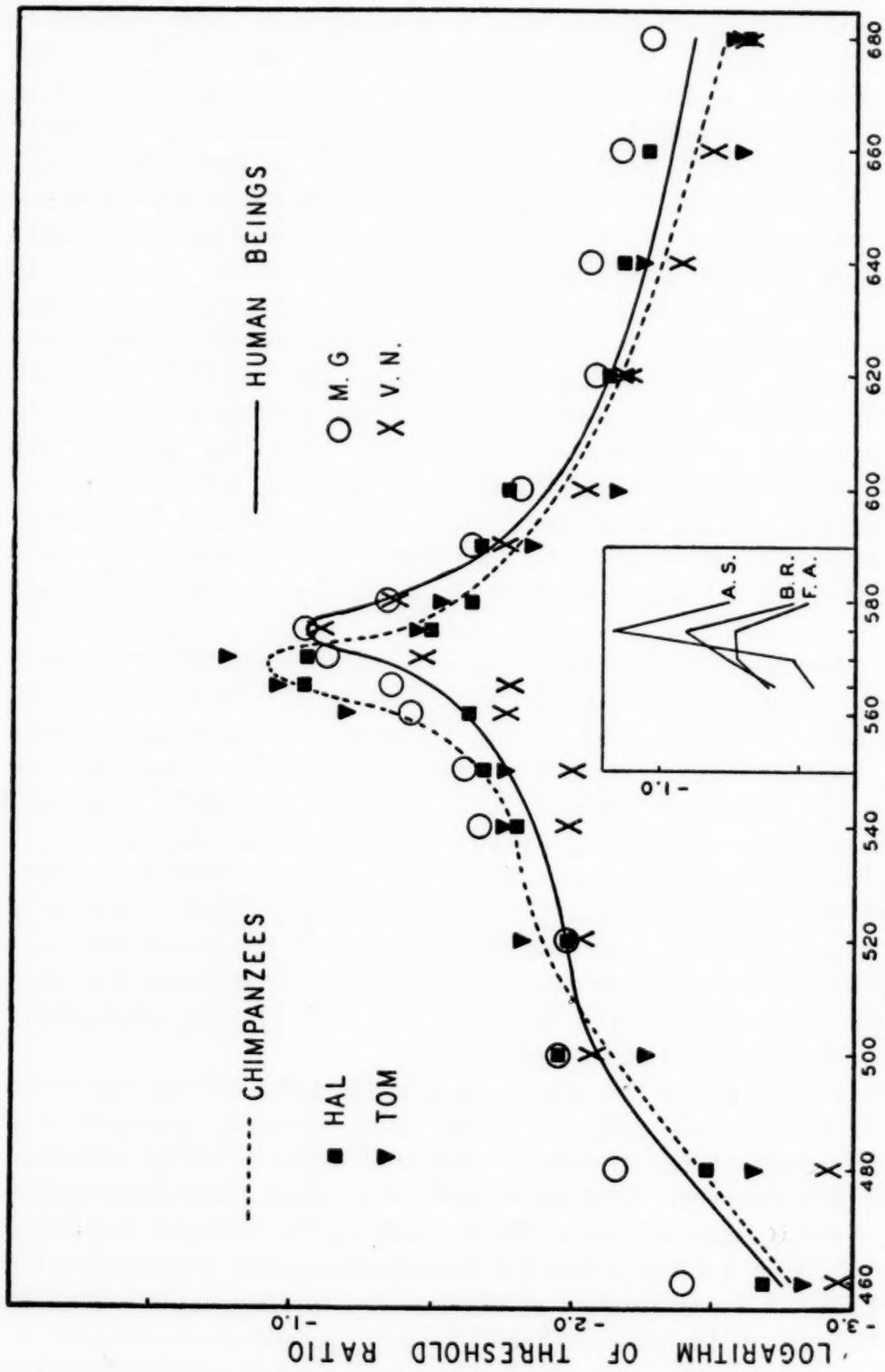


FIG. 1. Spectral saturation curves for chimpanzees and human beings. Dash line, two chimpanzees. Solid line, two human beings. Insert shows peaks only of curves for three additional human subjects.

points of minimum saturation. The continuous falling off in either direction from the central peak indicates increasing saturation toward the spectral extremes.

Comparison with Earlier Data

The measurement of saturation of spectral colors has not been carried out for other infrahuman organisms. The results of the present study are, however, directly comparable with similar measurements made for human beings by several other investigators. Priest and Brickwedde (**10**, **11**) measured threshold ratios of spectral color added to white for their own eyes. Their threshold ratios are of the same order of magnitude as those found in the present study, and curves plotted from their data (see Hecht, **5**) are almost identical in form to those shown here in Fig. 1. Purdy (**12**), Martin, Warburton, and Morgan (**8**), Wright and Pitt (**14**), and Nelson (**9**) have published similar data, showing the same relations of spectral saturation with wave-length. These earlier studies are all in agreement in showing a clearly defined point of lowest saturation centering around 570 mμ. The location of this point for human subjects at 575 instead of 570 mμ in the present study is adequately accounted for by the use of a white light of color temperature 4029° K. instead of approximately 5400° K. as is usually used in such work.

Comparison of Chimpanzees and Human Beings

In comparing the chimpanzee and human subjects, we find overlapping of thresholds at all points except at the peaks of the curves. At 575 mμ the thresholds of all five human subjects are considerably higher than those for the apes. At 570 and 565 mμ this relationship is completely reversed. Statistical analysis yields probabilities of .08, .03, and .01 — that the differences between human beings and chimpanzees at 575, 570, and 565 mμ respectively could have resulted by chance. Within the limits of the experimental method, therefore, there appears to be a 5-mμ difference in the location of the point of lowest spectral saturation for chimpanzee and man.

Of particular significance and importance is the virtual coincidence of the peaks of these saturation curves with the points in the spectrum at which the color reversal occurred. For the chimpanzees, it will be recalled, the greatest difficulty in discrimination was at 570 mμ, while at 565 mμ they spontaneously reversed their habit. For the human subjects the greatest difficulty in discrimination was at 575 mμ, and at 570 mμ the mixture of spectral color and white appeared slightly greenish.

beings. Insert shows peaks only of curves for three additional human subjects.

Interpretation of Color Reversal

The reversal of the discrimination habit of the chimpanzees at the spectral color most closely resembling white deserves special consideration. Though we cannot name or describe the actual color sensations for the chimpanzees, we can assume that for them there was a color change similar if not identical to the shift from reddish to greenish hue experienced by the human subjects. Even if such a color change did occur, why should the formerly negative white suddenly assume the properties of the reddish positive stimulus? Simultaneous contrast offers the most reasonable explanation of this reversal. The human subjects always reported the pure white to appear reddish when paired with a green and white mixture. That the same contrast effect occurred for the chimpanzees is quite likely since it has been demonstrated (Grether, **4**) that these animals are affected by simultaneous contrast in the same way as man. It might be pointed out, in this connection, that in one of the earlier experiments on color mixtures (**2**) a similar habit reversal occurred. When the color mixture was more reddish than the comparison white it was chosen as the positive cue. When the mixture was slightly blue-greenish the animals spontaneously reversed their habit and consistently chose the white.

Relation of Results to Young-Helmholtz Color Vision Theory

For the sharply defined point of lowest spectral saturation at about 575 mμ, and the coincident change in hue from reddish to greenish, a ready explanation can be found in the three excitation curves of the Young-Helmholtz theory. For these the reader is referred to Troland (**13**, p. 682) who gives the excitation curves adopted as standard by the Optical Society of America. The red and green curves, as the reader can easily verify, cross at about 572 mμ, almost precisely the wave-length at which we find the lowest saturation and the shift from reddish to greenish hue. The crossing of the excitation curves indicates that at this particular part of the spectrum the red and green receptor mechanisms are stimulated in the same proportions as by daylight. At this point, therefore, the color must be white minus virtually all of the blue component (since the blue curve is very low at this wave-length). Blue, it can be shown, contributes considerably less to the sensation of white than do red and green. (See Hecht, **5**, p. 796, for excitation curves in terms of the luminosities of the three primary colors.) For this reason the crossing of the red and green excitation curves must mark a spectral point of greatest white resemblance [*i.e.*, lowest saturation].

The actual experimental findings of the present investigation, and of earlier studies with human subjects, are, therefore, in remarkable agreement with predictions from the Young-Helmholtz theory regarding spectral saturation.

For the shift from reddish to greenish hue reported by the human subjects, and inferred for the chimpanzees from their reversal of the discrimination habit, the Young-Helmholtz excitation curves also provide an immediately obvious explanation. In passing from the point of lowest saturation toward the longer wave-lengths the proportional excitation of the red mechanism increases, hence the report of a reddish hue and a progressive increase in spectral saturation. Toward the shorter wave-lengths the green sensation predominates, hence the greenish hue and another increase in saturation.

These relationships between the spectral saturation and color relationships, and the Young-Helmholtz excitation curves permit us to speculate concerning the excitation curves for the color vision of chimpanzee. The slightly different location of the saturation minimum and color reversal suggests that for chimpanzee the crossing point of the red and green excitation curves is shifted about 5 mμ toward the shorter wave-lengths. This could be an indication of any one of several differences in the excitation curves themselves. Either one alone, or both the red and green curves might be shifted toward the shorter wave-lengths. Any such shift of the curves would be expected to produce a corresponding shift in the area of maximal hue discrimination in this part of the spectrum since this, according to trichromatic color vision theory, is also marked by the crossing point of these two excitation curves. In an earlier paper (Grether, **3**) evidence has already been presented that hue discrimination of chimpanzees is equal to that of man except in the long wave-length end of the spectrum. The predicted effect on hue discrimination of a shift in the crossing point of the red and green excitation curves is, therefore, fully in agreement with already available data.

Without reference to any particular theory, however, we can point out how chimpanzee color vision deviates from that of man very slightly in the direction of red-green color blindness, or dichromatic vision. First, for chimpanzees, as for human beings with red-green color blindness, the greatest deviation from normal human hue discrimination is at the long wave-length end of the spectrum. Secondly, for chimpanzees, as for the red-green color blind, the point of lowest spectral saturation is displaced from the normal in the direction of shorter wave-lengths. It should be remembered, however, that for chimpanzees these deviations are relatively slight.

Concerning the Psychological Purity of Yellow

It is frequently asserted, as an argument opposed to the Young-Helmholtz theory, that yellow is a psychologically pure color, that subjectively it cannot be described as a greenish red. The verbal reports of the human subjects in the present experiment fail to confirm this characteristic of the yellow sensation. If a psychologically pure yellow exists in the spectrum there should be a certain region that can be described neither as reddish nor greenish. There was, however, no supra-threshold mixture of spectral yellow and white which the human subjects were not willing to describe as more reddish or greenish than the comparison white. The subjective uniqueness of spectral yellow as a color sensation was, therefore, not found to be true for the conditions of the present study.

Summary

Saturation thresholds were measured at seventeen spectral points by finding the proportion of spectral color mixed with white needed to produce a discriminable hue. Complete curves of spectral saturation as a function of wave-length were obtained for two chimpanzees and two human beings. Measurements in the central spectral region were obtained for three additional human subjects. The results of the investigation may be summarized as follows:

1. The saturation curves for both chimpanzees and human beings conformed very closely to similar curves for human beings reported by earlier investigators. The point of lowest saturation for human beings was at 575 mμ, for chimpanzees at 570 mμ, using a comparison white of 4029° K. color temperature. The saturation minima for chimpanzees and human beings, therefore, differed by 5 mμ.

2. Coincident with the point of lowest spectral saturation there was found to be a radical change in primary hue. This was evidenced for the chimpanzees by a spontaneous reversal of the discrimination habit. The human subjects reported a shift from reddish to greenish hue.

The results are interpreted in terms of the Young-Helmholtz color vision theory. The interpretation is ventured that for chimpanzees the crossing point of the red and green excitation curves is shifted about 5 mμ toward the shorter wave-lengths. It is pointed out, also, that in having the saturation minimum of the spectrum displaced toward the shorter wave-lengths chimpanzee vision slightly resembles human red-green color blindness.

(Manuscript received October 31, 1940)

References

1. Grether, W. F., Color vision and color blindness in monkeys, *Comp. Psychol. Monogr.*, 1939, **15**, No. 4, 38.
2. ——, Chimpanzee color vision: I. Hue discrimination at three spectral points. II. Color mixture proportion. III. Spectral limits, *J. comp. Psychol.*, 1940, **29**, 167–192.
3. ——, A comparison of human and chimpanzee spectral hue discrimination curves, *J. exp. Psychol.*, 1940, **26**, 394–403.
4. ——, The magnitude of simultaneous color and brightness contrast for chimpanzee, *Psychol. Bull.*, 1940, **37**, 500.
5. Hecht, S., Vision: II. The nature of the photoreceptor process. In Murchison, C., *Handbook of general experimental psychology*, Worcester: Clark Univ. Press, 1934, 704–828.
6. —— and Shlaer, S., The color vision of dichromats: II. Saturation as the basis for wave-length discrimination and color mixture, *J. gen. Physiol.*, 1936, **20**, 83–93.
7. Jones, L. A., and Lowry, E. M., Retinal sensibility to saturation differences, *J. Opt. Soc. Amer.*, 1926, **13**, 25–34.
8. Martin, L. C., Warburton, F. L., and Morgan, W. J., The determination of the sensitiveness of the eye to differences in the saturation of colors, London: *Med. Res. Council, Reports of the Committee upon the Physiology of Vision*, XIII, Special Reports Series, 1933, No. 188.
9. Nelson, J. H., The colour-vision characteristics of a trichromat, *Proc. physiol. Soc., Lond.*, 1937, **49**, 332–337.
10. Priest, I. G., and Brickwedde, F. G., The minimum perceptible colorimetric purity as a function of dominant wave-length with sunlight as neutral standard, *J. opt. Soc. Amer.*, 1926, **13**, 306–307.
11. ——, The minimum perceptible colorimetric purity as a function of dominant wave length, *J. opt. Soc. Amer.*, 1938, **28**, 133–139.
12. Purdy, D. M., On the saturations and chromatic thresholds of the spectral colours, *Brit. J. Psychol.*, 1931, **21**, 283–313.
13. Troland, L. T., Vision: I. Visual phenomena and their stimulus correlations. In Murchison, C., *Handbook of general experimental psychology*, Worcester: Clark Univ. Press, 1934, 653–703.
14. Wright, W. D., and Pitt, F. G. H., The saturation-discrimination of two trichromats, *Proc. physiol. Soc., Lond.*, 1937, **49**, 329–331.

MEASURES OF INDIVIDUAL DIFFERENCES IN SUSCEPTIBILITY TO CONDITIONING[1]

BY ARTHUR A. LUMSDAINE

Princeton University

Problems related to the ease with which individuals form conditioned responses are of both practical and theoretical interest. In designing experimental procedures we may need information as to the probable number of trials that will be required for establishing a stable conditioned response. This illustrates the practical desirability of some sort of guiding standard. The theoretical importance of the distribution of ease of conditioning is shown by the occasional report that many individuals do not develop conditioned responses at all. If this is true there arises at least one serious objection to basing theories of learning on the facts of conditioning experiments.

The present study is concerned with individual differences in the ease of establishing conditioned eyelid responses in man, and supplements the results earlier reported by Campbell and Hilgard (**3**). By combining available data from this and from seven other investigations, conditioning records for at least 50 acquisition trials under comparable though not identical circumstances were obtained for 209 adult human subjects. In all cases the unconditioned response was the eyelid reflex to a puff of air and the conditioned stimulus was a flash of light preceding the puff by an interval of either 400 or 600 msec. All trials were reinforced; anticipatory conditioned lid responses were recorded photographically. In the case of five of the studies (**3, 5, 6, 7, 8**), embracing a total of 118 subjects, the original data were available; in the remaining three studies (**2, 9, 10**) data in a greater or less stage of condensation had to be used. All of the results here presented are based on records for as many subjects as was permitted by the availability of data on the particular measures under consideration.

Commonly used measures of the strength of conditioning include frequency of conditioned responses in a specified number of trials, number of trials required to reach an arbitrary criterion (such as 5 CRs), amplitude of CR, and latency of CR. The last two measures were not considered in the present study since differences in experimental conditions made the data insufficiently comparable in these respects. Fairly high correlations between amplitude of

[1] The writer is indebted to Dr. E. R. Hilgard of Stanford University for supplying most of the data on which this study is based, as well as for helpful suggestions and criticisms.

response and frequency or criterion measures, based on parts of the data here considered, were reported by Campbell (**2**) and by Campbell and Hilgard (**3**). These authors also presented distributions showing individual differences in latency and amplitude of response.

Distributions of Frequency and Criterion Measures

The combined data substantiate in general the conclusions of Campbell and Hilgard based on 63 of the cases included in the present study. Wide individual differences are found in the rapidity and extent of acquisition of conditioned eyelid responses, but practically all subjects show some degree of conditioning. The distribution for 209 subjects of the frequency of conditioned responses given in the first 50 trials is shown in Fig. 1. The number of trials on which conditioned responses appear is expressed as a percent of the total number of trials considered. The median frequency of response is 45 percent. The approximately rectangular form of this distribution will later be compared with other distributions of frequency scores.

Figure 2 shows the distribution for 117 subjects of the number of trials required to reach a criterion of 5 conditioned responses (not necessarily appearing on consecutive trials). Of the 118 subjects for whom original data were available, 110 (93 percent) reached this criterion in 60 trials or less. Three other subjects reached the criterion before the 100th trial and one failed to do so, while for the remaining four subjects no records were taken after the 60th trial. The tail of the distribution has been dotted in accordance with the apparent tendency for the high criterion-scores to spread out about evenly from the 60th to the 100th trial. The median number of trials to reach this criterion is 28. When more stringent criteria are employed the mode of the distribution shifts to the right. The median number of trials to reach the criterion of 4 conditioned responses within 5 consecutive trials is 32; to reach the tenth conditioned response, 37.

The average performance of a group in acquiring a conditioned response can be shown in the form of learning curves of the Vincent type (**4**). The progress of conditioning can also be exhibited, in somewhat more complete fashion, through progressive shifts in the form of the distribution of frequency scores. Figure 3 shows the distribution for 143 subjects in the first 20 conditioning trials. There is a marked positive skew. The median frequency of conditioned responses is 16 percent. Figure 4 shows the distribution for the same subjects at a later stage, on trials 31–50 inclusive. The direction of skewness has been reversed and the median frequency

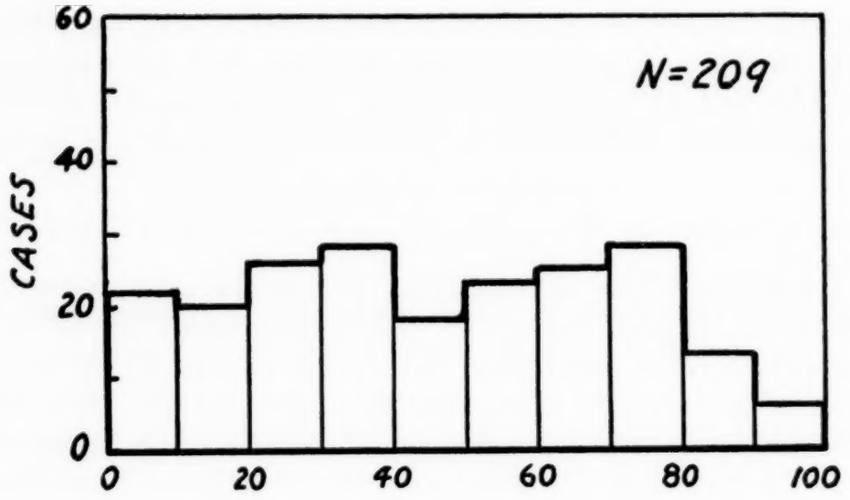


FIG. 1. FREQUENCY (%)
[50 Trials]

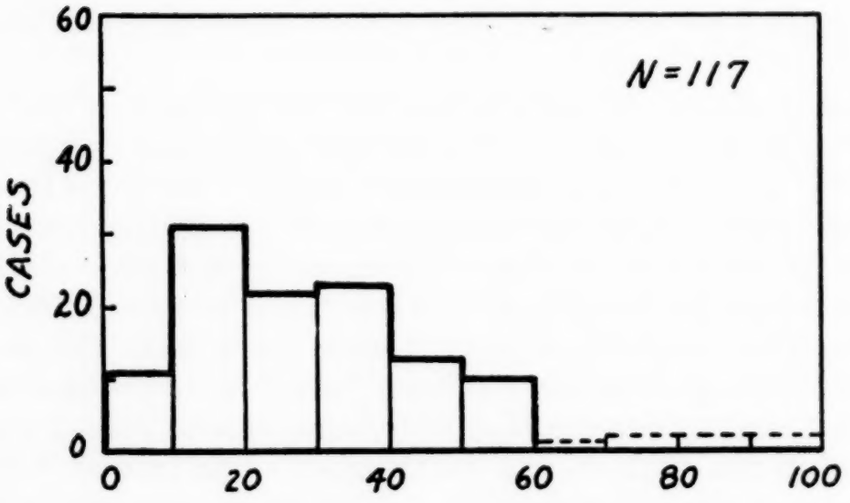


FIG. 2 CRITERION (Trials)

FIGS. 1 and 2. Distributions showing individual differences in susceptibility to the formation of conditioned eyelid responses.
FIG. 1. Relative frequency of trials on which conditioned responses appear.
FIG. 2. Number of trials to reach a criterion of 5 conditioned responses.

has increased to 64 percent. The essentially flat distribution of frequency scores in Fig. 1 may be interpreted as representing a stage intermediate between those of Figs. 3 and 4. The distribution for 63 subjects at a still more advanced stage (trials 51–100) is shown in Fig. 5; the median frequency is now 87 percent and the negative skew is even more extreme, with 60 percent of the subjects giving frequency scores above 80 percent.

It is unfortunate that such distributions cannot be directly

compared with those obtained with different responses or organisms, or even with those found for human eyelid conditioning with materially different experimental conditions. Effective differences may exist in the stimuli used, the sensitivity of the recording device, the instructions given the subject, and so forth. These differences may affect frequency and criterion measures as well as those of amplitude or latency. For example, disparity in distributions of frequency of conditioned eyelid responses for the subjects of Bernstein (1) and those of Campbell and Hilgard (3) have been reported by the latter

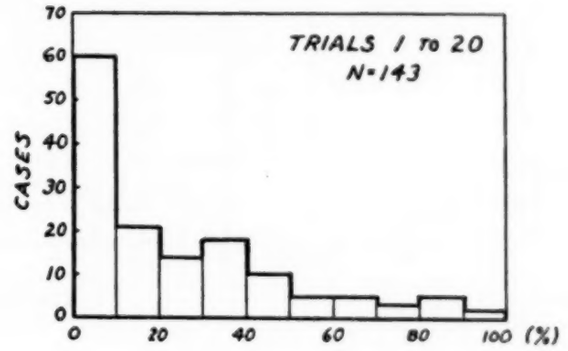


Figure 3

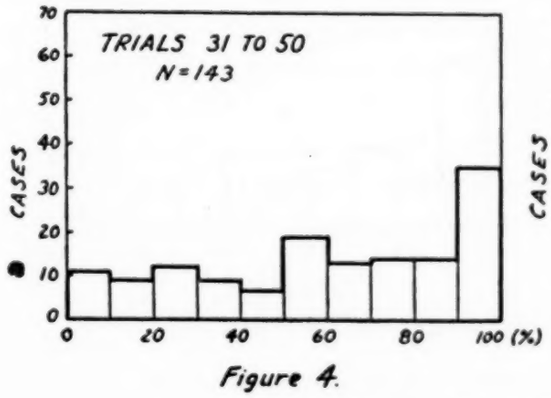


Figure 4.

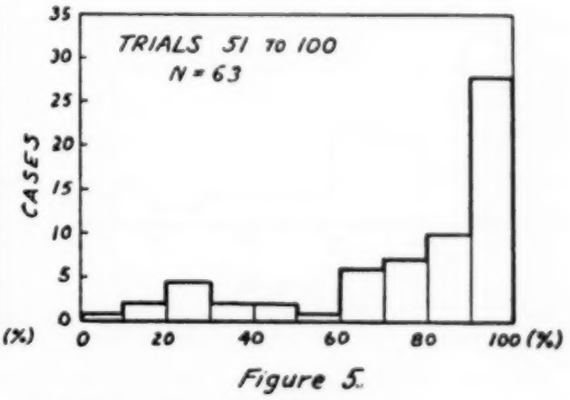


Figure 5.

FREQUENCY OF CONDITIONED RESPONSES

FIGS. 3, 4, 5. Acquisition of tendency to give conditioned eyelid responses as shown by distributions of frequency measures at three stages of training.

authors, from whom Figs. 6, 7 and 8 are reproduced. Comparison of Figs. 6 and 7 shows that Campbell and Hilgard's subjects evidence a much greater degree of conditioning by the end of 50 trials than do Bernstein's subjects. The median frequency scores are 19 percent and 49 percent. In fact, the extent of conditioning shown for the Bernstein subjects after *50* trials is about comparable to that for the Campbell and Hilgard group after only *20* trials (median score, 25 percent), as a comparison of Figs. 6 and 8 reveals. While the disparity could conceivably reflect a real difference in the 'condition-

ability' of the two groups of subjects, it seems more reasonable to look for an explanation in terms of discrepancies in experimental conditions. Both the conditioned and unconditioned stimuli used were different in the two studies and it is almost certain that Bernstein's pneumatic recorder was less sensitive than the photographic device used in the other case. To investigate the changes that would result simply from the use of a less sensitive recording technique, the Campbell and Hilgard data were re-calculated, omitting

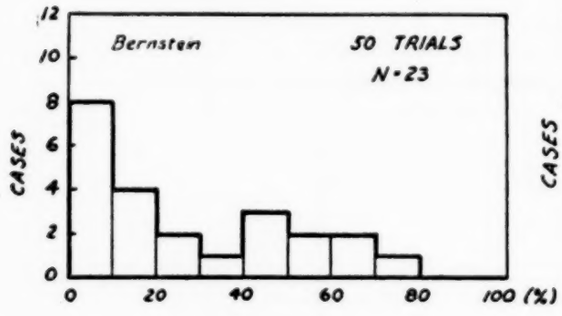


Figure 6.

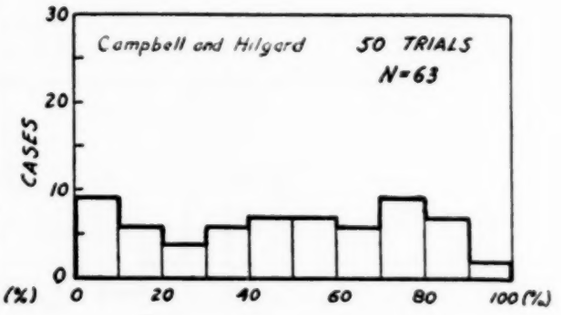


Figure 7.

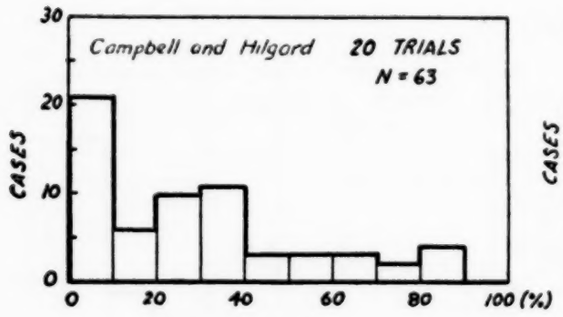


Figure 8.

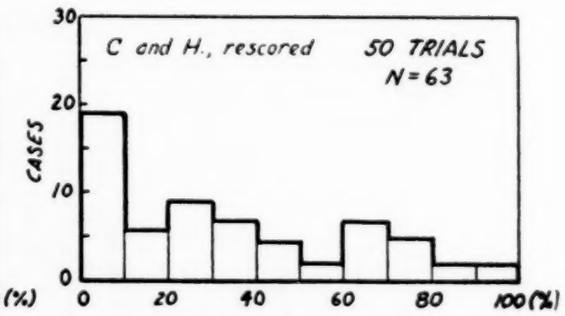


Figure 9.

FREQUENCY OF CONDITIONED RESPONSES

FIGS. 6, 7, 8, 9. Distributions of frequency of conditioned responses obtained in two investigations.

FIG. 6. Frequency of conditioned eyelid responses on trials 1 to 50. Based on data from Bernstein (1).

FIGS. 7 and 8. Frequencies of conditioned eyelid responses on trials 1 to 50 and on trials 1 to 20, respectively. From Campbell and Hilgard (3).

FIG. 9. Frequency of conditioned eyelid responses based on the same records as Fig. 7, but rescored to show the effect of using a less sensitive recording device.

from the scores all responses of very small amplitude.[2] The resulting distribution of frequency scores for 50 trials shown in Fig. 9 is much more comparable to that obtained by Bernstein than is the original distribution in Fig. 7. The median of the re-calculated scores is 28 percent. While some of the difference between the two studies

[2] Responses of 3 mm or less amplitude as measured on the records were omitted; probably all were considerably less than 1 mm in actual lid excursion.

may have arisen from the use of unlike stimuli, it is apparent that much of the observed disparity might be attributed to the effects of unequal sensitivities of the recording devices.

Reliabilities and Interrelations of Measures

Reliability coefficients of .80 to .90 for frequency and amplitude measures were reported by Campbell and Hilgard (3), based on 100 trials for 63 subjects.[3] In the present investigation, computation of a measure of reliability for scores of 118 subjects on the first 50 trials gave a Pearsonian coefficient of $r = .91$ for the correlation between frequencies of conditioned responses on odd-numbered and on even-numbered trials. Application of the Spearman-Brown formula yields a reliability coefficient of .96 for the frequency scores based on all 50 trials. For a given set of criterion scores it is of course impossible to compute a reliability coefficient, since there is but one measure available for each individual. However, some relevant information may be obtained by intercorrelating frequency scores and scores expressing the number of trials needed to reach criteria of various degrees of severity. The correlation coefficient for number of trials to the fifth conditioned response vs. number of trials to the tenth is .96, to '4 out of 5 consecutive' it is .90; and the correlation between the first criterion and the frequency scores (on Trials 1–50) is $-.89$.[4] Although such coefficients are based on partially common data and cannot be employed directly as measures of reliability, they do indicate that easily obtained criterion scores furnish a fair prediction of scores in terms of frequency or of more rigid criteria.

For the economical design of conditioning programs it is helpful to know whether the amount of conditioning shown by a subject in the first few trials is indicative of the amount that will develop at a later stage. An experimenter may wish, for example, to obtain as expeditiously as possible a group all members of which will exhibit fairly stable conditioned responses. Is it better for this purpose to discard those who are 'slow to learn,' or is further training likely to bring them to the desired level of performance? While an answer is in part contingent on the needs and procedures of the individual experimenter, as well as on other factors such as the availability of additional subjects, some tentative suggestions are afforded by the present data. It is apparent from Figs. 3, 4 and 5 that merely because a good proportion of subjects show little evidence of condi-

[3] These coefficients were obtained by comparing the middle segment of trials (Trials 26–75) with the first and last quarter of trials (Trials 1–25 and 76–100), and are not stepped up.

[4] These are product-moment coefficients based on approximately 100 cases.

tioning at first there is no positive guarantee that most of the group will not acquire stable conditioned responses if given more trials. This statement of the tendency for the group as a whole may be amplified to admit of some degree of individual prediction. A correlation table for frequency scores of 143 subjects on trials 1 to 20 and their corresponding scores on trials 31 to 50 yields a slightly curvilinear regression for predicting late from early scores (r = .60, eta = .66). While these values are not very high, inspection of the scatter diagram showed that for many subjects much better prediction is possible than would be inferred from the numerical correlation values alone. The scatter is of 'triangular' shape, such that nearly all of the cases fall above the diagonal of the table. This means that prediction is very poor for individuals making very low initial scores, but that an individual giving conditioned responses of moderate or high frequency in the early trials may very confidently be predicted to continue to show stable conditioning. With the present data it is possible to choose a critical frequency score of 30 percent in the first 20 trials, such that *all* individuals exceeding this score will yield from 50 percent to 100 percent conditioned responses in trials 31 to 50. That is, by discarding all subjects showing relatively little conditioning in the early trials, the experimenter may be assured of stable conditioning in all remaining subjects. On the other hand, such a procedure might be wasteful, especially if the supply of subjects were limited, since a low score in the first trials does not *necessarily* mean a low score after continued training.

Summary

By combining records from a number of previous studies, data were obtained for 209 adult human subjects for studying individual differences in the acquisition of conditioned eyelid responses. The data warrant the following conclusions:

1. Although wide individual differences in ease of conditioning are found, practically all individuals show some degree of conditioning by the end of 50 reinforced trials, contrary to the common assertion that many subjects do not show any evidence of conditioning in laboratory situations.

2. Group changes in the extent of conditioning at different stages are exhibited in progressive shifts in the distribution of frequency scores. The distribution is positively skewed in early trials, negatively skewed in later trials.

3. Differences in the amount of conditioning reported by different investigators may arise from varying experimental conditions. Differences in a specific instance are mainly resolved by correcting

for the inequality believed to exist in the sensitivity of the recording devices used by two experimenters.

4. The reliability of scores based on frequency of conditioned responses compares favorably with that of measures of individual differences in other fields. The reliability coefficient for frequency scores based on 50 trials was found to be $r = .96$.

5. Individuals who give fairly frequent conditioned responses in early trials may be confidently predicted to show continued stable conditioning; individuals giving low initial frequency scores may or may not develop more stable conditioning after more training.

(Manuscript received November 9, 1940)

References

1. Bernstein, A. L., Temporal factors in the formation of conditioned eyelid reactions in human subjects, *J. gen. Psychol.*, 1934, **10**, 173–197.
2. Campbell, A. A., The interrelations of two measures of conditioning in man, *J. exp. Psychol.*, 1938, **22**, 225–243.
3. Campbell, A. A., and Hilgard, E. R., Individual differences in ease of conditioning, *J. exp. Psychol.*, 1936, **19**, 561–571.
4. Hilgard, E. R., and Campbell, A. A., Vincent curves of conditioning, *J. exp. Psychol.*, 1937, **21**, 310–319.
5. Hilgard, E. R., Campbell, A. A., and Sears, W. N., Conditioned discrimination: the development of discrimination with and without verbal report, *Amer. J. Psychol.*, 1937, **49**, 564–580.
6. Hilgard, E. R., Campbell, R. K., and Sears, W. N., Conditioned discrimination: the effect of knowledge of stimulus-relationships, *Amer. J. Psychol.*, 1938, **51**, 498–506.
7. Hilgard, E. R., and Humphreys, L. G., The effect of supporting and antagonistic voluntary instructions on conditioned discrimination, *J. exp. Psychol.*, 1938, **22**, 291–304.
8. Hilgard, E. R., and Humphreys, L. G., The retention of conditioned discrimination in man, *J. gen. Psychol.*, 1938, **19**, 111–125.
9. Humphreys, L. G., The effect of random alternation of reinforcement on the acquisition and extinction of conditioned eyelid reactions, *J. exp. Psychol.*, 1939, **25**, 141–158.
10. Miller, J., The effect of facilatory and inhibitory attitudes on eyelid conditioning, Ph.D. dissertation, Yale University, 1939. (Abstr. in *Psychol. Bull.*, 1939, **36**, 577–578.)

METHODOLOGY IN THE CLINICAL MEASUREMENT OF EXCITABILITY

BY JACQUES S. GOTTLIEB AND O. D. FOWLER

Iowa State Psychopathic Hospital

In a previous note the technique of clinical measurements of excitability was discussed (3). Using the technique described, the much discussed question of the validity of chronaxie measurements as an index of excitability has again arisen. The controversial points have been well summarized by Davis and Forbes (1), and studies by Knoefel (4) and others have indicated that a single point on the intensity-time curve may not serve adequately as an excitability index.

A series of clinical experiments upon normal subjects and mental patients, under control conditions and under the influence of drugs, was made (2), using the modified electrode described. No significant differences were obtained under the conditions imposed, when rheobase and chronaxie measurements were taken in the conventional manner, and when repetitive stimuli were employed. For this reason it seemed wise to investigate entire intensity-time curves while employing the same technique.

Results

Figure 1 represents intensity time curves for single stimuli, taken on the same subject on different days. Two determinations of the curve were made on one day and three determinations on the other day, at intervals of several minutes.

(*a*) The curves taken on the same day show close agreement, possibly within experimental error.

(*b*) The curves taken on different days have the same general form.

(*c*) The curves taken on different days appear to be superimposable by shifting them along the intensity axis.

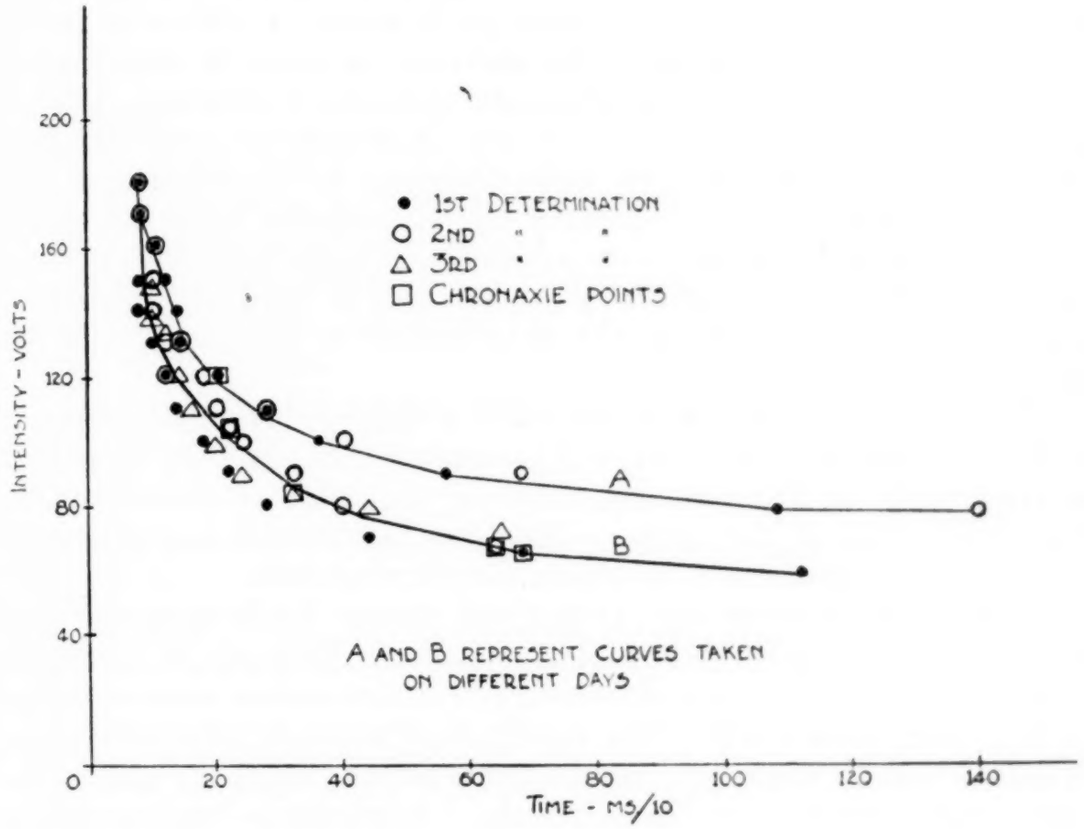
(*d*) While the points which were determined as chronaxie points fall on the curves, their location on the curve varies widely.

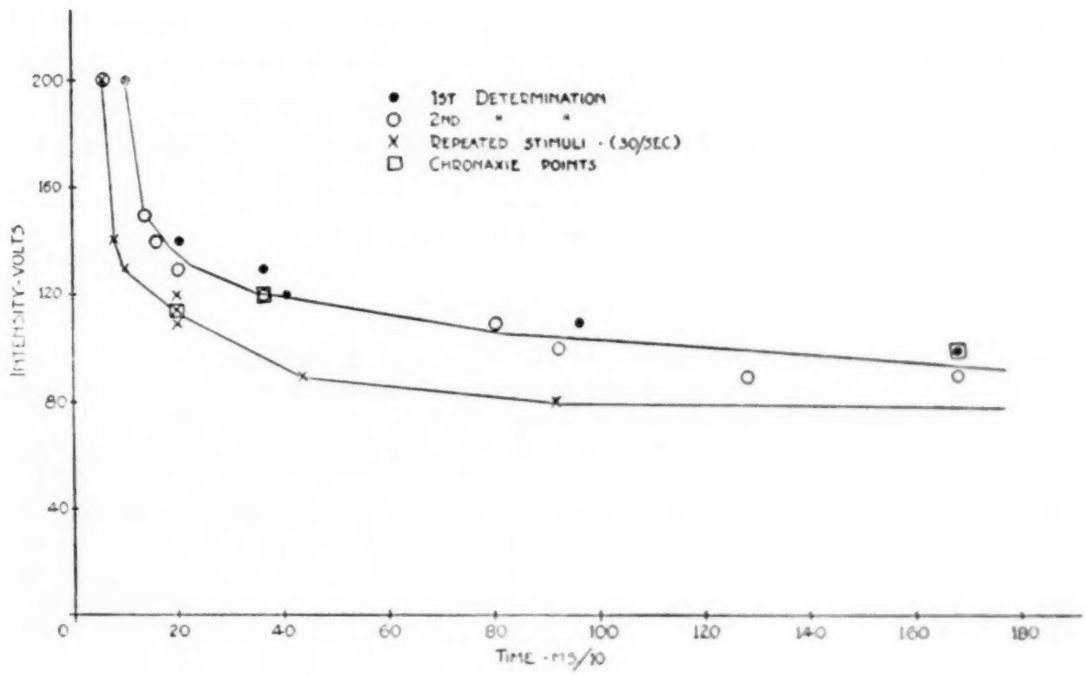
Figure 2 shows intensity-time curves for single stimuli and for repeated stimuli of a frequency of 30 per second. Two determinations of the curve for single stimuli and one determination of the curve for repeated stimuli were made successively on one subject.

The following points may be noted:

(*a*) The curve for repeated stimuli possesses a form similar to that for single stimuli.

(*b*) The curve for repeated stimuli falls at lower intensity values than the curve for single stimuli.





(*c*) The curves for single and repeated stimuli appear to be superimposable by vertical shifting along the intensity axis.

(*d*) While the chronaxie points fall on the curves, there is a great amount of disparity in their relative positions.

It is evident that any value, taken as rheobase, will when doubled give a point on the curve. There is, however, a difficulty in determining the true rheobase. In addition, an error in determining the rheobase will be doubled when the intensity is doubled, giving a point which falls upon the curve within experimental error, but with twice the experimental error with reference to its location as the 'true' chronaxie point. Whatever the explanation is, it is obvious that the experimental chronaxie points differ widely from the expected values, rendering them practically worthless as indices. Possibly a slight vertical shift during the determinations would account for these results.

The amount of shifting of the curve with repeated stimuli remains to be investigated. The effect of increasing the frequency of stimuli is apparently to decrease the intensity required, as shown by the downward shift of the curve. The time factor does not appear to be implicated, as there is no obvious horizontal shift.

It has been pointed out (1) that the change involved in the shift from the chronaxie of 'subordination' to the chronaxie of 'constitution' now appears to be a decrease in intensity rather than a change in the time factor itself. The results here reported with single and repeated stimuli appear to be analogous to conditions of 'subordination' and 'constitution,' respectively. A plausible explanation is that the peripheral condition of the nerve-muscle complex in the 'constitutional' state is duplicated by using repeated stimuli. In the one case, increased peripheral stimulation is brought about by removal of the inhibitory influence of the higher centers, while in the other case the increased stimulation is applied directly at the periphery.

(Manuscript received October 7, 1940)

References

1. Davis, H., and Forbes, A., Chronaxie, *Physiol. Rev.*, 1936, **16**, 407–442.
2. Fowler, O. D., Neurophysiological and psychological changes induced by certain drugs: I. Responses to electrical stimulation, *J. exp. Psychol.*, 1940, **27**, 657–668.
3. Gottlieb, J. S., and Fowler, O. D., A note on chronaxic technique, *J. exp. Psychol.*, 1941, **28**, 367–370.
4. Knoefel, P. K., Narcosis and the chronaxie, *J. Pharmacol. exp. Therap.*, 1935, **55**, 72.

THE PREFERENCE OF TWENTY-FIVE NEGRO COLLEGE WOMEN FOR MAJOR AND MINOR CHORDS

BY ORAN W. EAGLESON AND LILLIAN E. TAYLOR

Spelman College

Problem

This paper presents data from a group of Negro college women on their preferences for certain major and minor chords.

In a previous study the authors (1) obtained judgments for twelve different musical intervals, and compared these with somewhat similar data which Valentine (2) had collected from a group of white college women.

The data from the present study are compared with the preferences of the other two studies.

Procedure

The subjects for this study were twenty-five Negro college women of sophomore standing. The median age was seventeen.

The data were collected in 1940 on the nineteenth, twenty-first, twenty-third, twenty-sixth, and twenty-eighth of February, and the first of March. This distribution of sittings permitted a more reliable determination of the subjects' preferences for the major and minor chords. All subjects were present on each day.

The piano was used to present the following chords according to the method of paired comparisons: major third, major sixth, major second, major seventh, minor third, minor sixth, minor seventh, and minor second. The same pattern was followed in constructing the chords for this study that was described in a previous paper (1). Each chord was compared twice each sitting with each of the other seven, thus making a total of fifty-six comparisons at a sitting.

Results

The judgments were compiled in such a way as to enable the construction of Table I, which shows the distribution of judgments

TABLE I

The Distribution of Judgments for the Six Sittings Considered Collectively

Chords	Place								Total
	1	2	3	4	5	6	7	8	
Major third	68	43	15	17	4	3			150
Major sixth	28	46	34	28	14				150
Minor third	24	37	34	33	16	5	1		150
Minor sixth	23	26	36	39	16	10			150
Major second	16	14	15	22	57	22	4		150
Minor seventh	1	3	8	16	29	76	13	4	150
Major seventh					5	16	108	21	150
Minor second		2	3		1	9	23	112	150

for the six sittings considered together. From the data it was possible to assign places from *1* to *8* to each of the eight chords. First place or *1* meant the chord was preferred by most of the subjects most of the time. Second place or *2* meant the chord was the next preferred interval, and, similarly, a place of *8* meant the chord was preferred least of the eight chords by most of the subjects most of the time. As one may see, when the judgments for twenty-five subjects for six sittings were compiled there were 150 judgments for each chord.

The critical ratio was computed for the difference between each chord and the subsequent one in order to determine the reliability of the positions assigned to the musical intervals. A critical ratio of 4.6 revealed that the major third was significantly more preferred than the major sixth, and for that reason the former chord could be considered undoubtedly the most preferred for the subjects in this study. The major sixth and minor third were not reliably different in the places assigned them, having a critical ratio of 1.97; a similar difference was found between the minor third and minor sixth, the critical ratio being 1.35. From these results it seems in order to conclude that the ranks assigned to these three chords are not certain. The major second, minor seventh, major seventh, and minor second, however, are reliably placed, since the critical ratios of the differences involving these chords range from about 3.01 to over 7.

It is interesting to note that there are certain similarities between the findings in this study and the results of another study which the authors (1) have published previously. In the earlier paper it was pointed out that there was definite agreement on the part of the subjects in that study and the subjects in a study by Valentine (2) as to the ranks for the least preferred chords, while there was little agreement in the two studies as to the ranks assigned to the most preferred chords. This same conclusion might now be extended to include the present results. Table II has been prepared to show the findings in the three studies.

When the rank order formula for determining correlation was applied to the data in the present study and to only the positions of the major and minor chords in the previously published study a correlation of .79 was obtained. On the other hand when the present data were correlated with Valentine's results a correlation of .98 was found. This fact points out the close agreement between the data of the present study and the results of Valentine.

When the preferences were analyzed for each of the six days, it was found that the major second, minor seventh, major seventh, and minor second were ranked on each of these days in fifth, sixth,

seventh, and eighth places respectively, and each rank was found to be statistically significant. The other four places—first, second, third, and fourth—were given to the major third, major sixth, minor third, and minor sixth respectively, but the difference between each of these and the subsequent chord was not always statistically reliable.

TABLE II

THE FINDINGS FOR THREE STUDIES IN WHICH JUDGMENTS ON THE MAJOR AND MINOR CHORDS HAVE BEEN SECURED

Rank	The Authors' Previous Study of 75 Negro Women with Data Collected at One Sitting	The Authors' Present Study of 25 Negro Women with Data Collected at Six Sittings	Valentine's Study of 84 White Women with Data Collected at One Sitting
1	Triad	Major third	Major third
2	Minor third	Major sixth	Minor third
3	Minor sixth	Minor third	Major sixth
4	Major sixth	Minor sixth	Octave
5	Fifth	Major second	Minor sixth
6	Fourth	Minor seventh	Fourth
7	Major third	Major seventh	Tritone
8	Octave	Minor second	Fifth
9	Major second		Major second
10	Minor seventh		Minor seventh
11	Major seventh		Major seventh
12	Minor second		Minor second

SUMMARY AND CONCLUSION

1. Twenty-five Negro college women expressed by the method of paired comparisons their preferences for eight major and minor chords which were played on the piano. All the subjects were examined on six different days. The findings were then compared with similar data obtained from a study of white college women by Valentine and a study of Negro college women by the authors.

2. The twenty-five Negro women judged the eight chords in the following order from the most preferred to the least preferred: major third, major sixth, minor third, minor sixth, major second, minor seventh, major seventh, and minor second. This same order of preference was found for each of the six days as well as for the six days considered collectively.

3. The data for the six days when brought together revealed the major third to be preferred over the major sixth by a difference which was statistically reliable; however, the major sixth was not reliably preferred over the minor third nor the minor third over the minor sixth. On the other hand, the least preferred chords—major second, minor seventh, major seventh, and minor second—were each reliably preferred in the order given.

4. In the authors' previous study, in Valentine's study, and in the present one there is absolute agreement on the least preferred chords, but the findings of each study differed from those of the other two concerning the chords which were most preferred. The present data, however, agree much more closely with Valentine's findings than with the data from the authors' previous study.

(Manuscript received November 1, 1940)

References

1. Eagleson, O. W., and Taylor, L. E., A study of chord preference in a group of Negro college women, *J. exp. Psychol.*, 1940, **26**, 619–621.
2. Valentine, C. W., The æsthetic appreciation of musical intervals among school children and adults, *Brit. J. Psychol.*, 1913, **6**, 190–216.

SIMPLIFIED PHOTOELECTRONIC RECORDER, TIMER, AND STIMULUS CONTROL DEVICES

BY ROGER BROWN LOUCKS

University of Washington

Photoelectronic Recorder

In 1938, the writer published a description of a capacitance pick-up device to be used in conjunction with a long-persistence cathode ray oscilloscope for recording tissue displacements such as eyelid or limb movements, or plethysmographic changes (1). The capacitance pick-up technique is superior to most photographic recording systems in that the experimental subject need not be completely immobilized. For example, when the capacitance system is used to record eyelid movements, the subject's head need not be fixed. The pick-up device is small and light enough to be supported on a head no larger than that of the rabbit and turns with each movement of the head. A second advantage is that the fluorescent trace on the screen of the oscilloscope, because of its long persistence, can be studied visually at the same time it is being photographed. The experimenter does not have to wait until his photographic records are developed to find out precisely what reactions his subject is giving. Furthermore, the record on the oscilloscope screen persists long enough to be traced manually (either in ink, on cellophane, or by means of a pantograph system). Most of the expense and labor connected with the usual technique of photographic recording can be eliminated by using manually traced records for all routine responses of the subject. Occasional photographs may be taken to check the accuracy of the corresponding manually traced record.[1]

A very considerable simplification, electrically, is obtained by substituting for the capacitance pick-up device, noted above, a photoelectronic pick-up consisting merely of one phototube and one triode vacuum tube, which feeds directly into the long-persistence cathode ray oscilloscope (Fig. 1). This photoelectronic system has

[1] Excellent photographic records can be made with Agfa Superpan Press and a Baby Brownie ($1.00) camera. (An inexpensive magnifying glass is used as a portrait attachment.) Approximately 35 eyelid records can be made perpendicular to the long dimension of an eight exposure film ($1\frac{5}{8} \times 2\frac{1}{2}$). If all recording is to be photographic, Eastman No. 697 recording paper should be used. This costs approximately 1.2 cents per hundred feet for 35 mm width and 1.7 for 60 mm width. Recording paper gives very satisfactory records provided a fast lens is used. (An uncorrected lens two inches in diameter with a speed of F/1.2 can be ground for approximately five dollars and is quite adequate for this type of work.) In this connection see reference by McCulloch and Wendt (2).

The simultaneous recording of several responses is discussed in the last section of this paper.

almost unlimited sensitivity and yet is so flexible that it is perfectly adapted for recording gross limb movements. Like the capacitance pick-up device, it makes possible the recording of eyelid movements when the subject's head is not immobilized.

To record the eyelid movements of, *e.g.*, a rabbit, an RCA No. 922 vacuum phototube is fastened to a bakelite base 1.5 mm thick. The bakelite base is turned up at one end as shown in Fig. 2. (It is molded by holding it against a hot soldering iron.) This bent

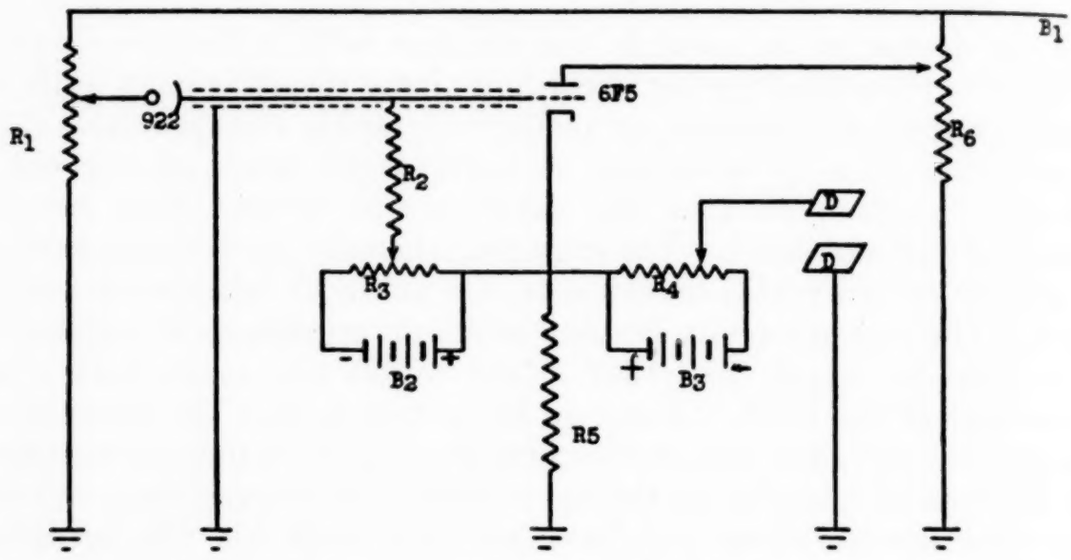


FIG. 1. Photocell pick-up unit.

R_1 = 500 M., Phototube anode voltage control.
R_2 = 5 megohm, Phototube load resistor.
R_3 = 20 M., Grid bias control.
R_4 = 500 M., Bucking voltage control, to govern position of trace at start of record.
R_5 = 1 megohm cathode load resistor.
R_6 = 500 M., Triode plate voltage control.
D = Deflecting plates of cathode ray oscilloscope.
B_1 = 300 v., Triode and photocell high voltage supply.
B_2 = 10 v., Grid bias.
B_3 = 150 v., Bucking voltage to force trace to edge of oscilloscope so total width of screen may be used in recording.
$6F5$ = High mu triode.
922 = RCA vacuum phototube.

Note: Lead from cathode of photocell to grid of triode must be well shielded. Excitor lamp for photocell is 2.2 focusing flashlight bulb, not shown. It may be supplied by one cell of storage battery. A small variable resistor in series with lamp gives flexibility of control.

end forms the support for the excitor lamp. A celluloid shutter, moved by the eyelid, controls the amount of light falling on the phototube. The shutter is mounted on an axle which turns in jewel bearings. (The axle and bearings can be taken from an old watch or obtained from an electrical instrument company.) The bearings are supported in a Y-shaped plastic (Tenite) post mounted on the bakelite base, just to one side of the phototube. Eyelid movements

are transmitted to the shutter by means of a narrow strip of celluloid which fits over a very small pin at the outer tip of the shutter arm.

To obtain uniform illumination of the photocell without utilizing an elaborate lens system is something of a problem. After consider-

FIG. 2. Sketch of phototube pick-up assembly.

A = Adhesive tape.
B = Bakelite base of phototube unit (1.5 mm thickness).
C = Cathode lead to phototube.
D = Ground celluloid diffusion screen, opaque except arc-shaped translucent window.
L = Focusing flashlight bulb, base removed; head pressed into bakelite strip.
P = Plastic post (Tenite) which supports jewel bearings.
S = Arc shaped shutter moved by eyelid.
T = RCA No. 922 vacuum phototube, 15/16ths × 1⅜ths approx.
W = Silver wire (No. 26 B. & S.) shock electrode.
R = Sponge rubber padding.

able experimentation, it was found that reasonably uniform illumination could be obtained by using a 2.2 volt flashlight bulb with thickened glass tip, which serves as a lens, in conjunction with a ground celluloid diffusion screen. The screen is cemented to the

post holding the jewel bearings. It is painted opaque except for a small arc-shaped, translucent window which admits light to the sensitive surface of the photocell.

To fasten the photoelectronic pick-up device to the rabbit's head, a piece of adhesive tape is warmed on an electric light bulb. The tape is then stuck to a closely clipped area of scalp over the bregma. The bakelite base of the photounit is fastened permanently, by thread and flexible collodion, to a second piece of adhesive tape. This second piece of tape, *i.e.*, the base of the unit, is cemented to the adhesive strip on the scalp by non-flexible collodion. The electric shock, the unconditional stimulus, used to force lid closure, is administered to the cheek through a sterling silver wire (No. 26 B. & S. gauge). This electrode is held in position by being secured to the base that supports the phototube and excitor light.

To insure a straightline relationship between a displacement of the shutter and the corresponding deflection of the fluorescent spot on the oscilloscope, the grid bias of the 6F5 triode must be set at its appropriate voltage. The whole system can be calibrated very simply by means of an inexpensive Starrett tachometer. The tachometer has a reduction gear ratio of 100 to 1. During a calibration the opaque shutter of the pick-up device is driven by means of watch gears from a shaft screwed into the hub of the tachometer. To calibrate the system, the experimenter manually turns the long shaft of the tachometer and notes the angular displacement of the tachometer (and hence that of the shutter) in relation to a linear movement of the electron beam on the oscilloscope.

In recording foot movements two types of shutter have been experimented with. One consists of a thin bakelite strip which has been cut out to make a supporting frame for a sheet of ground celluloid. The celluloid has a long narrow triangular window which is translucent, the background being blacked in. This whole frame is fastened to the rabbit's foot by means of a light strap, and slides up and down in a grooved guide, just in front of the photocell. The second type of shutter is similar to the device used as the eyelid recorder but is constructed of heavier material. The arc-shaped shutter has less friction and inertia and seems generally superior to the sliding shutter.

To record respiration of a rabbit, a technique has been worked out in conjunction with Mr. James C. Welch, in which the animal is enclosed within a box which has an opening fitting snugly about his neck. (The rabbit, unlike most animals, lies quietly within such a box and seldom struggles.) A small conduit leads from the box to a tambour. Pressure changes within the box arising from the rabbit's respiration create corresponding displacements in the dia-

phragm of the tambour. These movements can be recorded on the long-trace oscilloscope by merely connecting the shutter of the photounit described for eyelid recording to the diaphragm of the tambour. If greater sensitivity is desired, a small mirror can be connected to the diaphragm of the tambour in such a way that a slight excursion of the diaphragm produces an angular displacement of a beam of light. With adequate spacing of the mirror and photocell, almost any degree of sensitivity can be obtained. This technique has such sensitivity that it is particularly suited for recording the various phenomena of pulse and blood pressure.

Photocell Timer

The photocell timer to be described consists, in part, of a transparent Tenite cylinder, seven inches high and six inches in diameter, which is rotated in vertical position by a synchronous phonograph motor. A series of photocells are mounted one above the other at the outer edge of the cylinder. Focusing flashlight bulbs are supported in a fixed position inside the cylinder and serve as excitor lamps for the respective photocells. Black photographic Scotch tape, one inch in width, is fastened in parallel strips on the outside of the transparent cylinder. As the cylinder revolves about its verticle axis, openings in the opaque strips admit light to the respective photocells. Associated with each photocell is a vacuum tube which either serves as an electronic relay by itself, or directly actuates an electromagnetic relay. The electronic and electromagnetic relays act as switches which control the various stimuli that are administered to an animal in a conditional response training routine. Because the cylinder makes one revolution in approximately eight-tenths of a second, it is difficult to close and open a manual master switch at the appropriate point in the cycle of signal and reinforcing stimuli. As a consequence, a disc is geared to the shaft which turns the cylinder, so as to make one revolution for every four revolutions of the cylinder. This disc controls a master photocell unit. When a master switch is manually closed, the master photocell unit is actuated during every fourth revolution of the cylinder. The triode vacuum tube controlled by the master phototube directly energizes an electromagnetic relay (Fig. 3) which switches the high D.C. voltages on or off the plates and anodes of all photocell units controlled by the cylinder with the exception of the sweep unit. The individual circuits of the photocell timer are shown in the accompanying diagrams.

Photocell Sweep Circuit

The relaxation-oscillator type of sweep circuit, used in most oscilloscopes, is unstable at slow rates. As a consequence, a photocell

unit is employed to sweep the electron beam of the oscilloscope. The circuit is the same as that used for the pick-up device, shown in Fig. 1, and consists merely of one photocell and one triode. Changing the brightness of the excitor light, by means of a small variable resistor, alters the amplitude of sweep. Changing the value of the bucking potential (R_4, Fig. 1) governs the position of the starting point of the sweep. The opaque photographic tape which controls the amount of light falling on the sweep phototube is cut so as to

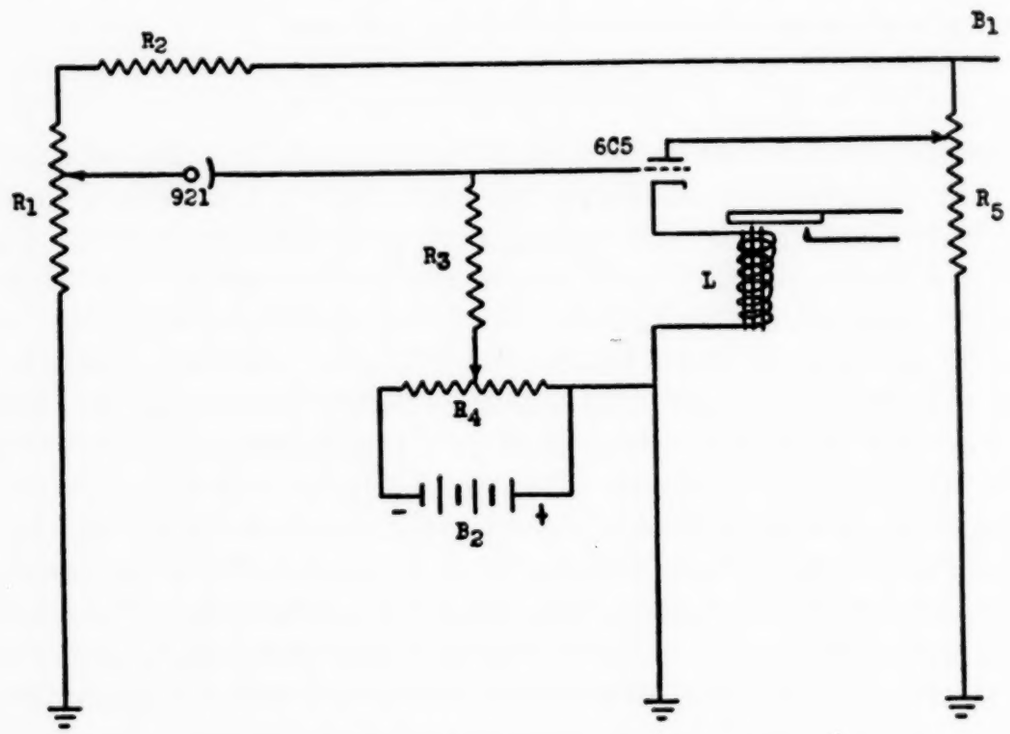


FIG. 3. Photoelectromagnetic relay circuit.

R_1 = 100 M.
R_2 = 400 M.
R_3 = 5 megohms.
R_4 = 25 M.
R_5 = 500 M.
B_1 = 400 v.
B_2 = 22.5 v.
L = 3000 ohm, 12 milliwatt, Struthers Dunn Relay (Phila.).
921 = RCA Gas phototube.

provide a long narrow triangular window the circumference of the cylinder. (A ground celluloid diffusion screen, placed just in front of the photocell, insures a relatively uniform light field.)

Figure 3 shows the circuit of a photocell unit which controls the brilliance of the trace on the fluorescent screen of the oscilloscope. A band of photographic tape governs the action of this unit so that the intensity is increased only during the forward sweep of the electron beam on that particular revolution of the cylinder in which

the stimuli are administered. At all other times the electron beam produces a faint trace. The return of the beam to the starting point of the sweep, following each revolution, results in only a quickly fading line which is easily distinguished from the slower movement of the forward sweep.

Photoelectronic Control of Electrical Stimuli

Muenzinger and Walz (3) have noted the increase in stability of shock when a pentode with appropriate biases is used to limit the current. A special problem arises, however, in connection with conditioning procedures. When electrodes are in permanent contact with the subject, and the current to these electrodes must be switched on and off, there are transient voltage surges which arise at the make and break of the circuit. These transients tend to be very irregular even when the circuit is closed by an electromagnetic relay. As seen on an oscilloscope, the voltage peaks are many times the height of the average D.C. shock impulse. This causes an irregularity in the amplitude of unconditional response. The surges are still present when the shock is controlled by a switch in series with the primary of the power transformer.

A fairly adequate solution of this difficulty can be achieved by placing the subject in parallel with the switch that controls the shock. The subject is in parallel with the switch and in series with the plate circuit of the pentode. When the switch is closed, the subject is not being shocked. The pentode plate current flows through the low resistance path provided by the switch and only an infinitesimal portion of the current flows through the subject's tissues, which constitute a high resistance in parallel with the switch. When the switch is opened the current can no longer pass through the switch but must be carried by the tissues between the two electrodes. There are no appreciable surge effects because the plate circuit is not actually broken. The only irregularity with this system is in the duration of shock. Electromagnetic relays tend to be somewhat variable in action. When the subject receives a shock that is about one-tenth second duration there can be quite appreciable variation in the unconditional response merely from a slight temporal irregularity in closure of the relay.

These difficulties, inherent in a mechanical or electromagnetic switch, can be obviated by employing a sharp cut-off pentode, *e.g.*, a 6J7, as an electronic switch (Fig. 4). The plate current, which causes the shock, is controlled by means of the grid. The subject remains continuously in the plate circuit but receives a shock only when the bias voltage of the grid is reduced. An ideal method of administering the shock is to control the 6J7 by means of a photocell

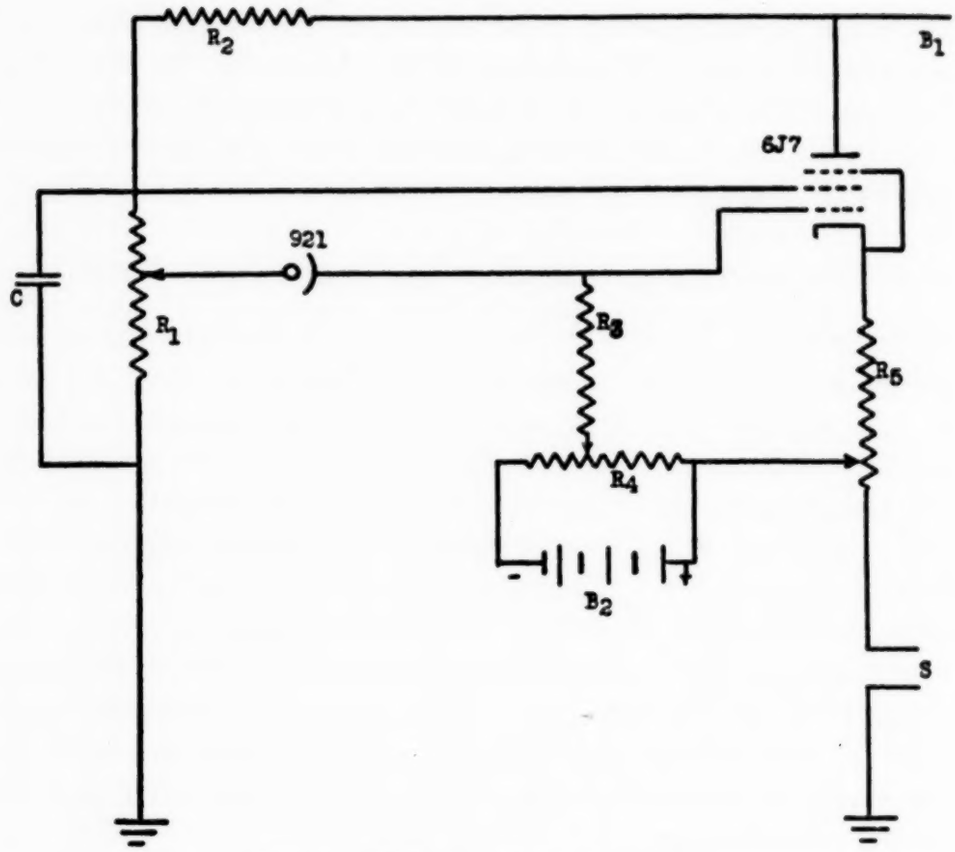


FIG. 4. Photoelectric shock control.

R_1 = 100 M.
R_2 = 250 M.
R_3 = 5 megohms.
R_4 = 20 M.
R_5 = 25 M.
S = Leads to subject's electrodes.
C = .5 microfarad, 400 volt paper condenser.
B_1 = 400 v.
B_2 = 22.5 v.

and timer such as that described above. The duration and number of D.C. shocks is governed by the pattern cut in one of the strips of opaque tape on the outside of the transparent cylinder. As the strip of tape rotates between the excitor light and the photocell a point is reached where, *e.g.*, five, regularly spaced gaps appear. As each gap passes the photocell the grid bias of the 6J7 pentode is reduced and a D.C. impulse flows through the plate circuit and tissues of the experimental subject. There are no irregular surges. The amplitude of shock can be continuously varied by means of a potentiometer in the cathode circuit of the pentode.

PHOTOELECTRONIC CONTROL OF ONSET AND TERMINATION OF AUDITORY SIGNALS

When an auditory stimulus such as the pure tone from an audio-frequency generator is turned on and off by means of a mechanical

switch there are irregular transients which are heard as clicks. These irregular clicks render the tone, considering it as a conditional stimulus, a variable factor in the training routine. For some time the writer has employed a 6J7 as an electronic switch on the output side of an oscillator to control onset and termination of the auditory stimuli. Tripping a switch causes a condenser to charge or discharge through a fixed resistance. The voltage on the condenser governs the bias of the 6J7 and thus controls the volume of tone passed by the pentode. With this technique the tone can be started and stopped logarithmically. This method has the disadvantage, however, that with any particular capacitance-resistance combination, a change in frequency of signal causes a change in the period of time required for the tone to build up to maximum amplitude or to cut off to the inaudible point.

I am indebted to Mr. Myron H. Swarm, an electrical engineer, for the tone control circuit shown in Fig. 5, which may be used in

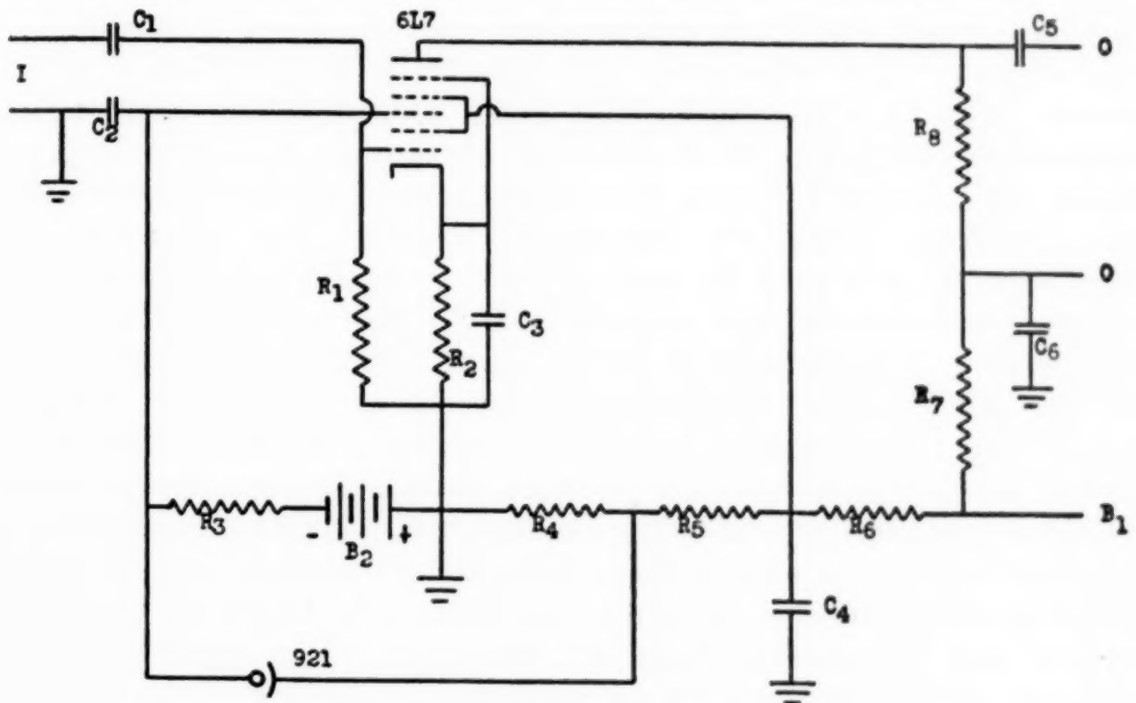


FIG. 5. Photoelectronic tone control.

C_1 = .5 microfarad.
C_2 = .01 microfarad.
C_3 = .1 microfarad.
C_4 = .5 microfarad.
C_5 = .5 microfarad.
C_6 = .5 microfarad.
R_1 = 50 M.
R_2 = .3 M.
R_3 = 2 megohms.
R_4 = 8 M.
R_5 = 15 M.
R_6 = 15 M.
R_7 = 15 M.
R_8 = 50 M.

B_1 = 350 v.
B_2 = 45 v.
O = Output to phones or speaker transformer.
I = Input from audio oscillator.
921 = RCA Gas phototube.

conjunction with a photoelectric timer such as that described above. Briefly, the pattern cut in a strip of paper carried by the revolving transparent cylinder governs the amount of light which falls on a photocell. This photocell controls the bias on the master grid of a 6L7 vacuum tube which acts as an electronic switch for the output of the audio oscillator. The circuit employs but one vacuum tube in addition to the photocell. It is very stable in action and any pattern of volume change that might be desired can be produced by merely cutting the appropriate mask of photographic tape. Clicks are entirely eliminated and the no-light condition completely blocks the tone from the loud speaker or phones.

Simultaneous Recording of Several Reactions

It is sometimes erroneously supposed that the cathode ray oscilloscope is capable of registering but one trace at a time. The Western Electric Company manufactures a cathode ray tube, No. 330, which has three independent electron beams focusing upon one screen. This tube costs approximately $196 exclusive of the power supply. (The three-inch tube used by the writer costs approximately $21.) It is possible, moreover, to use any single beam oscilloscope to trace two independent records by employing the DuMont Type 185 Electronic Switch. For example, one photoelectric unit may be used to pick up eyelid movements and a second photoelectric unit may be used to pick up foot movements. The output of both units is led to the electronic switch and thence to the oscilloscope. The switch electronically shifts (in approximately 25 microseconds) from one pick-up channel to the other. The effect is that of two independent records simultaneously traced on the fluorescent screen of the oscilloscope. (With the addition of a second electronic switch three independent records can be traced simultaneously on one screen.) In using the DuMont electronic switch one precaution must be observed. The photoelectronic pick-up units described above produce fluctuating D.C. voltages that are frequently non-sinusoidal. Three condensers inside the DuMont switch box must be disconnected to prevent distortion of record. Two condensers, numbers C7 and C8,[2] are 4-mfd. capacities connected between ground and the screen grids of the two 6C6 tubes. The third condenser that must be disconnected is C9, a 24-mfd. capacitance connected between ground and the junction of R16 and R17. (Resistance R16 is the one which is connected to the plus output binding post.) Unless these condensers are disconnected

[2] The notation is that of the wiring diagram for the DuMont electronic switch which accompanies the instruction manual (Date: Nov. 15, 1938).

there is considerable distortion, *i.e.*, smoothing, of the transient voltages produced by the photoelectronic units in the recording of eyelid movements.

(Manuscript received November 22, 1940)

References

1. Loucks, R. B., Preliminary note on a general purpose recording technique, *J. Psychol.*, 1938, **6**, 243–245.
2. McCulloch, W. S., and Wendt, G. R., A photokymographic method with continuous cathode ray oscillograms, *Science*, 1936, **83**, 354–355.
3. Muenzinger, K. F., and Walz, F. C., An examination of electrical-current-stabilizing devices for psychological experiments, *J. gen. Psychol.*, 1934, **10**, 477–482.